LEVELS OF METALS AND METALLOTHIONEIN IN FISH OF THE COLUMBIA RIVER NEAR THE INTERNATIONAL BOUNDARY

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ABSTRACT

Concentrations of Hg, Cd, Cu, Pb, Zn and several other metals were measured in muscles and livers of fish from the Columbia River between the Hugh Keenleyside Dam and the International Boundary. Metal concentrations were evaluated in relation to guidelines for edible fish flesh and by comparison with levels in fish from other areas. Attempts were made to detect temporal trends in metal levels in fish tissues and to compare levels above and below the major known metal input, the effluent from Cominco Ltd. at Trail, British Columbia.

Concentrations of most metals in fish muscle did not exceed guidelines for edible fish flesh, but the mean Hg concentration in northern squawfish (Ptychocheilus oregonensis) exceeded the 0.5 µg/g (wet weight) Food and Drug Directorate guideline, and the mean mercury concentration in walleye (Stizostedion vitreum vitreum) approached that level. Concentrations of Pb in several largescale suckers (Catostomus macrocheilus) and in the single sturgeon (Acipenser transmontanus) collected exceeded 1 µg/g.

Concentrations of most metals were elevated by comparison with levels in fish from areas where no metal inputs have been identified, but were often lower than levels in fish from waters receiving major municipal and industrial discharges.

Concentrations of Hg, Cd, Cu, Pb and Zn were generally lower in fish caught upstream from Cominco than in fish caught downstream, but because of limited knowledge of the movement patterns of most fish species, it was impossible to draw firm conclusions from this observation.

Not enough data were available to show temporal trends in the concentrations of any metal in any fish species.

Concentrations of hepatic metallothionein in rainbow trout (Salmo gairdneri) were measured to provide an index of the effect of

environmental metal levels on the fish. The average metallothionein concentration in trout livers exceeded the 100 n mol/g which Roch and McCarter (1984b) have identified as indicating a "minimal biological effect". Thus, the fish apparently were stressed by metals, but the ecological effect of this stress on Columbia River fish has not been demonstrated.

Recommendations for a program of monitoring metals in Columbia River fish are made.

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I. INTRODUCTION

Since 1980, the Water Quality Branch, Inland Waters Directorate, and the British Columbia Ministry of Environment have been conducting a joint study of heavy metal concentrations in fish from the Columbia River upstream from the International Boundary. This study was initiated to compare levels of mercury, and other metals to guidelines for edible fish flesh. The work has been expanded to include trend monitoring, and it is anticipated that it may be continued as part of the joint Federal-Provincial monitoring program. Additionally, metallothionein levels in fish livers were measured as a potential indicator of environmental stress.

The major source of metals in this section of the Columbia River is Cominco Limited's lead-zinc smelter and fertilizer complex at Trail. In the 1970's Cominco was identified as the largest single source of mercury release (including both aquatic and atmospheric emissions) in the Pacific region (Garrett et al. 1980). Concentrations of cadmium, lead, mercury, and zinc which exceeded criteria for effects on aquatic life were occasionally measured at low flow in water downstream from Cominco (B.C. Ministry of Environment 1979). Elevated metal concentrations were also found in sediments, attached algae and invertebrates downstream from Cominco (B.C. Ministry of Environment 1979). Although most metal levels measured in fish muscle were below previous guidelines for edible fish flesh, concentrations of cadmium and lead in a few fish collected below Cominco exceeded the Canadian Food and Drug Directorate standards which were in force when the collections were made (B.C. Ministry of Environment 1977, 1979).

In the late 1970's Cominco began a modernization program designed to increase production and reduce metal discharges. These changes included an acid treatment plant which was added in 1981 and a mercury removal plant which opened in 1983 and was operating efficiently by 1985. The current study of metal levels in fish was carried out while these changes were being implemented.

II. STUDY OBJECTIVES

The primary objectives of this study were:

1) to evaluate concentrations of heavy metals, especially Hg, in fish in relation to Food and Drug Directorate Guidelines for edible fish flesh;
2) to compare metal levels in Columbia River fish with levels reported in fish from other areas;
3) to select the most desirable species for the purposes of establishing trends and recommend the frequency for monitoring.

Secondary objectives of the study were:

4) to monitor temporal trends in metal concentrations in fish tissues.
5) to compare concentrations of metals in fish collected above and below the major known metal input, the Cominco complex at Trail;
6) to evaluate sublethal effects on fish of elevated concentrations of metals in the environment.

Objectives 1-5 were addressed by monitoring concentrations of metals in muscle and liver tissue from several species of fish. Objective 6 was addressed by using metallothionein concentrations in livers of rainbow trout (Salmo gairdneri) as an index of the sublethal response of these fish to environmental metal levels.

The majority of this report is divided into two parts:

1) concentrations of heavy metals in fish tissues with emphasis on mercury and
2) metallothionein levels in rainbow trout livers.

The report concludes with a series of recommendations for an ongoing monitoring program.

III. STUDY AREA

A. Water Quantity and Quality

The study area generally encompasses the Columbia River from the Hugh Keenleyside Dam to the International Boundary with supplementary sampling sites at Norris Creek and Deer Creek (Fig. 1).

Discharge rates measured at the Water Survey of Canada gauging station at Birchbank are representative of water quantity in most of the study area. During the years when the present study was conducted (1980, 1981 and 1983) mean annual discharge rates at Birchbank ranged from 1690 m^3/s to 2280 m^3/s. The minimum daily discharge rate was 555 m^3/s measured on April 18, 1981, the maximum was 4790 m^3/s recorded on July 7, 1981 (Inland Waters Directorate, Water Survey of Canada 1980-1983).

Water quality in the study area has been monitored by both the B.C. Ministry of Environment and the Water Quality Branch of Environment Canada. The Ministry of Environment (1979) has summarized water quality data collected from 1975 to 1977 at several stations including Waneta and Birchbank. Extracts from these data along with Water Quality Branch Monitoring data for pH and hardness are listed in Table 1a. Water Quality Branch data for metals based on hourly samples taken during 24 to 72-h surveys are shown in Table 1b. High concentrations of metals in the water are an episodic occurrence which appears related to discharges from Cominco (Sheehan, personal communication).

The Ministry of Environment has also measured concentrations of metals in sediments and found significantly higher concentrations of metals downstream from Cominco than upstream. In 1976, maximum concentrations in sediments downstream from Cominco (µg/g dry weight) were Cd 8.3, Cu 1930, Pb 866, Zn

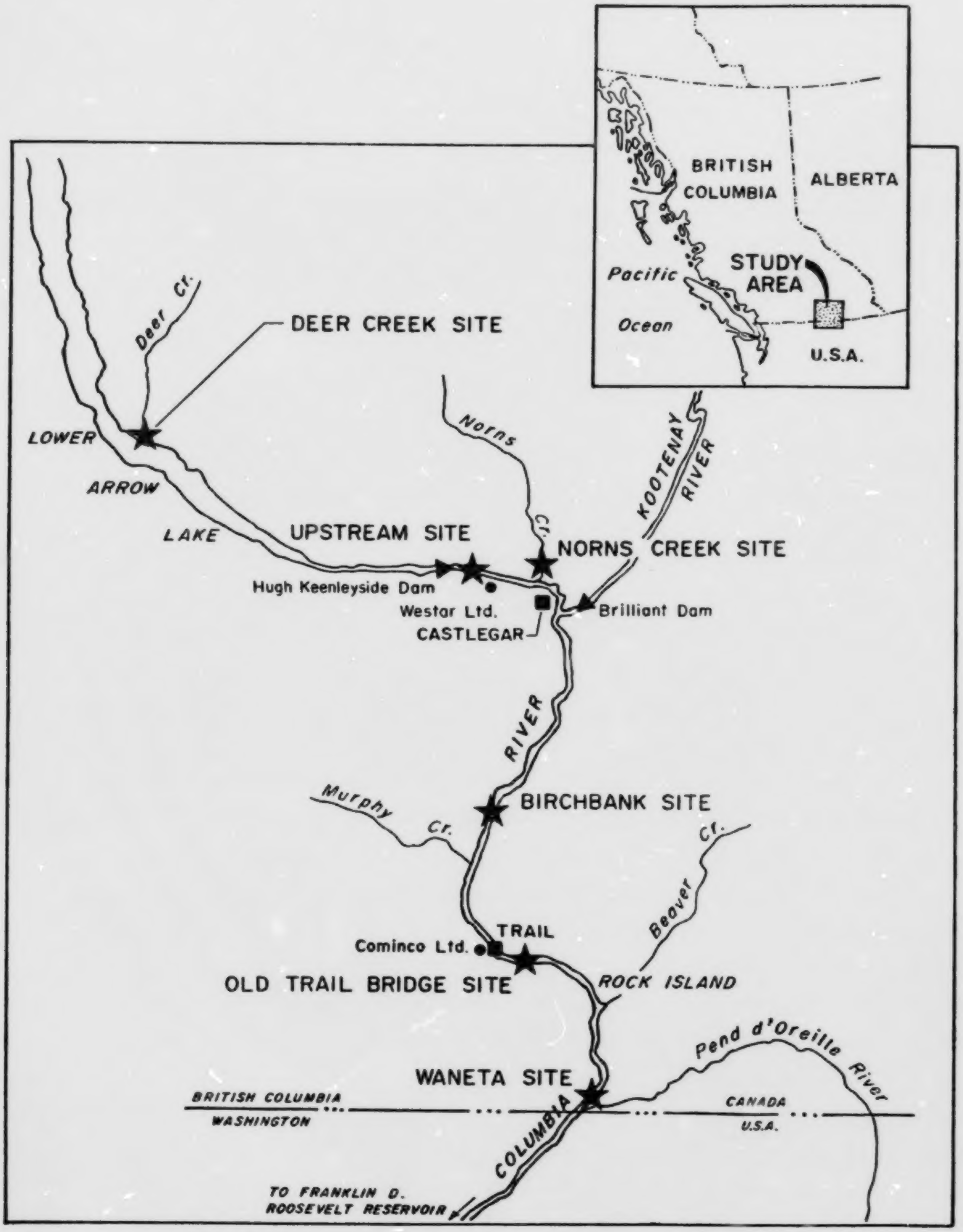
BRITISH COLUMBIA
ALBERTA
STUDY AREA
Pacific Ocean
U.S.A.
Deer Cr.
DEER CREEK SITE
LOWER ARROW LAKE
Norns Cr.
KOOTENAY RIVER
UPSTREAM SITE
NORNS CREEK SITE
Hugh Keenleyside Dam
Westar Ltd.
CASTLEGAR
Brilliant Dam
RIVER
Murphy Cr.
BIRCHBANK SITE
Beaver Cr.
TRAIL
Cominco Ltd.
OLD TRAIL BRIDGE SITE
ROCK ISLAND
Pend d'Oreille River
WANETA SITE
BRITISH COLUMBIA
WASHINGTON
CANADA
U.S.A.
COLUMBIA
TO FRANKLIN D. ROOSEVELT RESERVOIR

Figure 1 - Fish collection locations (★) in the Columbia River Basin, British Columbia

Table 1a

Water quality of the Columbia River at Birchbank and Waneta.
Data sources are MOE = B.C. Ministry of Environment (1979),
WQB = Water Quality Branch, unpublished data.

Site & Date/ Parameter		N	Mean	Range	Source
Birchbank, 06/1975 - 07/1977					
pH		52	8.0	7.5-8.4	MOE
Total Hardness	mg/L	27	59	44-72	MOE
Total Mercury	µg/L	24	<.05	<.05-.05	MOE
Total Cadmium	µg/L	12	.6	<.5-1.1	MOE
Dissolved Copper	mg/L	15	.001	<.001-.003	MOE
Total Lead	mg/L	12	.001	<.001-.003	MOE
Total Zinc	mg/L	12	.006	<.005-.019	MOE
Waneta, 06/1975 - 07/1977					
pH		23	7.9	7.4-8.3	MOE
Total Hardness	mg/L	12	65	45-78	MOE
Total Mercury	µg/L	12	.07	<.05-.15	MOE
Total Cadmium	µg/L	12	.6	<.5-1.7	MOE
Total Copper	mg/L	3	.001	<.001-.002	MOE
Total Lead	mg/L	12	.005	<.001-.018	MOE
Total Zinc	mg/L	12	.07	<.005-.32	MOE
Waneta, 01/1978 - 10/1982					
pH		86	7.7	7.3-8.3	WQB
Total Hardness	mg/L	86	64.3	49.3-84.6	WQB

Table 1b

Water quality of the Columbia River at Waneta: metals.
Water Quality Branch, unpublished data.

Metal/ Year	Sampling Duration	n	Median	Range
Cd (mg/g):				
1978	24 h	13	<.0005	<.0005 - .0008
1981	60 h	47	.0005	<.0005 - .0009
1983	72 h	66	<.001	<.001 - .012
Cu (mg/g):				
1978	24 h	13	.004	.003 - .004
1981	60 h	47	.003	<.001 - .04
1983	72 h	66	.005	.002 - .04
Hg (ug/g):				
1978	24 h	13	<.05	<.05 - <.05
1981	60 h	47	<.05	<.05 - .3*
1983	72 h	36	<.05	<.05 - .08*
Pb (mg/g):				
1978	24 h	13	.005	.003 - .007
1981	60 h	47	.004	<.001 - .012
1983	72 h	66	.007	.003 - .056
Zn (mg/g):				
1978	24 h	13	.04	.03 - .05
1981	60 h	47	.027	.014 - .07
1983	72 h	66	.024	.014 - .303

* value above detection found in one sample only

12 600, Hg (wet weight) 2.52 (B.C. Ministry of Environment 1979). Maximum sediment metal concentrations (reported as above) measured at the same locations following a mercury spill in April, 1980, were Cd 16, Cu 1957, Pb 2290 Zn 10 250, Hg 8.14 (B.C. Ministry of Environment, unpublished data).

B. Major Influences on Water Quality

The three known major effluents into the Columbia River in the study area are Westar's pulp and paper mill at Castlegar (formerly Canadian Cellulose), the Regional District of Kootenay sewage treatment plant downstream from Trail, and Cominco's lead-zinc smelter and fertilizer complex at Trail. The authors of the "Kootenay Air and Water Quality Study" (B.C. Ministry of Environment 1977, 1979) apparently did not consider Westar and the sewage treatment plant important sources of metals and did not report metal concentrations in their effluents. Although before 1970 some British Columbia pulp mills discharged mercury (from phenylmercuric acetate slimicides), Canadian Cellulose was not one of these (Garrett et al. 1980). Thus, Cominco is the primary source of metal inputs in the study area.

Between 1979 and 1983, Cominco implemented a series of changes in production methods and effluent treatments which reduced the amount of zinc and other metals discharged to the river. In 1983, a mercury removal plant was added; this plant was functioning efficiently by late 1984. Annual discharges of metals by Cominco, 1977-1985, are given in Table 2.

In addition to the metals listed in Table 2, Cominco discharges other metals which are considered less important components of the effluent and are monitored only by spot checks. Not enough data on these metals are available for inclusion in Table 2. One of the less-frequently monitored metals is copper, which was

Table 2

Average annual loss (kg/day) from Trail Metallurgical Sewers
Values are for total metals. Data supplied
by Cominco, Ltd.

Year	Zinc	Lead	Cadmium	Arsenic	Mercury
1977	8,444	254	95	10	7
1978	7,534	221	122	12	7
1979	7,173	210	77	10	5
1980	7,400	204	35	17	5
1981	5,211	159	28	13	2
1982	4,107	163	64	14	2.5
1983	2,100	105	41	14	2.5
1984	1,800	64	19	18	1.9
1985 (9 months)	1,200	65	29	18	1.2

discharged through one sewer before 1983, but which is now being recycled. Another such metal is chromium, which occurs in traces in phosphate rock and which is discharged in the fertilizer plant effluent (J. McCunn, personal communication).

IV. METALS IN FISH TISSUES

A. Introduction

Fish are frequently selected as monitor organisms for heavy metals for several reasons: 1) Consumption of contaminated fish can pose a threat to human health. 2) Measurement of metal concentrations in water or sediments gives no indication of bioavailability of the metals, while measurement of metals in organisms does indicate availability. 3) Concentrations of metals in water may undergo wide temporal fluctuations, making the results of infrequent water samples difficult to interpret. Concentrations of metals in fish tissues integrate these fluctuations over the lifespan of the fish, making interpretation of data possible with less frequent sampling.

Mercury concentrations in fish tissues have been monitored since the late 1960's when elevated (> 1.0 μg/g) mercury levels in fish were reported in Sweden (Johnels et al. 1967) and in Canada (Wobeser et al. 1970). Results of various monitoring programs have been brought together in overview reports of data from British Columbia and the Yukon (Garrett et al. 1980) and from across Canada (Sherbin 1979). A nation-wide monitoring program for mercury has been established in the United States (May and McKinney 1981). In addition, the results of many studies of mercury in fish from specific lakes and watersheds in Canada, the U.S. and Europe have been published.

Many surveys of mercury in fish tissues relate the levels found to concentrations harmful to human health. In 1969, Health and Welfare Canada established a guideline of 0.5 ppm (wet weight) total mercury in commercial fish (Sherbin 1979); this guideline remains in effect. Both Canadian and U.S. investigators discuss survey results in terms of whether mercury levels in fish exceed the 0.5 ppm limit (eg. Potter et al. 1975, Meister et al. 1979, Sherbin 1979, Akielaszek and Haines 1981, MacCrimmon et al. 1983).

Methods of reporting mercury levels in fish have become fairly standard both across Canada and internationally. Concentration is usually expressed as parts per million (i.e. µg/g) wet weight. For most monitoring studies, mercury is measured in muscle tissue, although the U.S. National Pesticides Monitoring Program (which includes monitoring for metals) uses homogenates of whole fish (May and McKinney 1981). Certain widely distributed species, including pike (Esox lucius) and walleye (Stizostedion vitreum vitreum), are frequently used for mercury monitoring, allowing comparisons among diverse watersheds.

Levels of other heavy metals in fish tissues have also been investigated. These studies include surveys of many metals in fish from individual lakes or watersheds (Lucas et al. 1970, Uthe and Bligh 1971, Mathis and Cummings 1973, Weiner and Geisy 1979, Wren et al. 1983), surveys of levels of a few metals in fish collected over wide areas (Lovett et al. 1972, Badsha and Goldspink 1982, Hakanson 1984) and measurements of metals in relation to specific problems (Murphy et al. 1979, Wilson et al. 1981, McFarlane and Franzin 1980, Czarnezki 1985).

In some cases, concentrations of other heavy metals in fish have been compared with "safe" levels for human consumption (eg. Uthe and Bligh 1971), but guidelines for metals other than mercury have been changed over time. For example, the Canadian Food and Drug tolerance level for lead in fish was 10 ppm wet weight (Canada Department of National Health and Welfare 1968), but was lowered to 2 ppm in 1974 and changed again in 1979 to 0.5 ppm in "fish protein". The Missouri Department of Conservation used a guideline of 0.3 ppm (wet weight) in edible fish flesh, which they derived from the World Health Organization's (1972) recommended consumption limit (Czarnezki, 1985). The Canadian Food and Drug Directorate has now abandoned established limits for metals other than mercury, and suspected cases of contamination are reviewed on a case by case basis (Environment Canada 1985).

There has been little consistency among studies in methods of reporting levels of metals other than mercury. Some authors express concentrations on a wet weight basis; others express concentrations as dry weights. Some investigators measure metals in muscle tissue, occasionally with intramuscular bones included (Uthe and Bligh 1971, Mathis and Cummings 1973, Czarnezki 1985); others use whole fish (Lucas et al. 1970, Weiner and Geisy 1979), while still others analyze liver or other organs (McFarlane and Franzin 1980). Thus, comparing data from different studies, even when the same metals have been measured in the same species, can be difficult.

There is not even agreement on the value of monitoring most metals in fish tissues. Phillips (1977) concludes that there is no justification for using fish as indicators of pollution by metals other than mercury. Nonetheless many scientists continue to support such monitoring. For example, the U.S. National Pesticides Monitoring Program (May and McKinney 1981) includes monitoring for arsenic, cadmium, lead and selenium in fish tissue.

In this chapter, concentrations of mercury and other heavy metals in fish collected from the Columbia River between the Hugh Keenleyside Dam and the confluence with the Pend d'Oreille River are reported. These levels are compared with concentrations of metals measured in fish from other watersheds and, where possible, with guidelines established for human consumption. Differences in concentrations in fish collected above and below the major metal input at Trail, B.C., are also considered. Later (Part VI), recommendations are made for metals and species to be included in future monitoring.

B. Collection Sites

Fish for metal analyses were collected from four major areas. Collections were made at the Old Trail Bridge to obtain fish exposed to the highest metal levels immediately downstream from the Cominco effluent. This site actually encompassed the stretch of river from the Cominco metallurgical sewers downstream to Beaver Creek. Collections were made downstream from Beaver Creek to the confluence with the Pend d'Oreille River (referred to as the Waneta site) to obtain fish exposed to the concentrations of metals crossing the International Boundary. Fish were also collected 9-14 km upstream from Trail near Birchbank and 6-10 km downstream from the Hugh Keenleyside dam. The locations of all these sites are shown in Figure 1.

C. Methods

1. Sampling Schedule

Water Quality Branch and Ministry of Environment personnel collected fish for metals analyses on three occasions. On August 5-6, 1980, fish were collected at Birchbank, Old Trail Bridge and Waneta (Figure 1). On November 2-3, 1981, collections were made at Old Trail Bridge and Waneta. On September 6-7, 1983, fish were collected from several sections of the river between the Cominco outfall and Waneta (See Appendix XIX).

Additional fish were collected between August 25 and September 6, 1981, by R.L. & L. Environmental Services. These collections were made near the Hugh Keenleyside Dam and at the Waneta site (actually near Beaver Creek). Some spawning kokanee (*Onchorhynchus nerka*) were also taken from Norns Creek (locally known as Pass Creek) and Deer Creek (Figure 1).

2. Other Data

Cominco has been conducting its own program of monitoring metal concentrations in Columbia River fish. Data from Cominco's 1980 and 1984 monitoring programs are included in this report.

The B.C. Fish and Wildlife Branch obtained one sample of muscle tissue from a white sturgeon (Acipenser transmontanus) which had been caught at Waneta on May 19, 1982. The results of analyses on this tissue are also included.

3. Collection Methods

Fish for all Federal-Provincial samples were collected by electroshocking. Collections were made from a 6-m aluminum river boat equipped with boom shocking capability. The electroshocking apparatus consisted of a Coffelt VVP-15 shocking unit with power supplied by a 3500 watt Honda generator. Power (5-7 amps, 400 volts) was dispersed through a boom apparatus.

Effective capture distance was approximately a 4-5-m radius off the bow of the boat and to a depth of about 3 m. Fish stunned by the shock surfaced. They were immediately picked up with long-handled dip nets and transferred to a holding bucket. All species which surfaced were collected except in 1983, when largescale suckers (Catostomus macrocheilus) were rejected.

In 1980 and 1981, fish were collected in daylight. Most of the 1983 collections were made after dark because of improved capture rates as fish moved inshore to shallower waters.

Most fish collected by R.L. & L. Environmental Services were taken by gill netting. All kokanee, except one fish, were found dead.

4. Sample Preparation

The fish were brought to a mobile field laboratory where they were identified to species, weighed, measured and dissected. Each fish was weighed on an Ohaus spring balance (2000 g capacity). It was placed on a measuring board and fork length was measured. The fish was then labelled with a numbered Floy tag.

Scales from each fish were removed and saved for age determinations. Otoliths were also removed from most individuals to obtain additional aging information.

When the fish were dissected, care was taken to avoid contamination with metals. Stainless steel scalpels were used for dissections. Between dissections scalpels were washed with dilute HNO_3 and distilled water to prevent transfer of metals among samples. Scientists wore rubber gloves which also were washed periodically with dilute HNO_3 and distilled water.

Muscle and liver tissues were removed for analysis. Fish were filletted, and one fillet from each fish was placed in an individually labelled, nitric acid-washed polypropylene tissue cup with a polyethylene lid. Livers were removed and placed in similar containers, but in most cases several livers from fish of the same species were composited to provide enough tissue for analysis. Tissues were stored in a refrigerator in the mobile lab and transferred to a freezer at the end of the day. Frozen samples were shipped on dry ice to various laboratories for analyses.

Some muscle samples were split and sent to two laboratories for quality control studies. In these cases either 1) the left and right fillets from a single fish were sent to different laboratories, or 2) one large fillet was divided in half, and anterior and posterior portions were sent to different laboratories.

5. Laboratory Analyses

a. Age Determination

Fish were aged at the Federal Fisheries Scale Laboratory. Determinations were made by counting annuli on scales (Alt 1969, Sebastian 1979). Ages were confirmed by examination of otoliths, when available (Bilton and Jenkinson, 1969).

b. Hg Analyses

Measurements of Hg in muscles of all fish and livers of most fish from Federal-Provincial and R.L. & L. Environmental Services collections were made at the B.C. Ministry of Environment Laboratory. Quality control determinations were made at the Environmental Protection Service (EPS) Vancouver Laboratory, the Water Quality Branch Vancouver Laboratory, and the National Water Quality Laboratory (Burlington). All of Cominco's samples were analyzed by Cominco. Samples analyzed by each laboratory are listed in Table 3. The analytical methods used by the different laboratories are summarized in Table 4.

c. Other Metals

Most analyses for other heavy metals were performed by either the EPS laboratory or the National Water Quality Laboratory. Some quality control analyses were done by the Water Quality Branch (Vancouver) Laboratory. Samples analyzed by each laboratory are listed in Table 3, and the analytical methods used are summarized in Table 5.

Table 3

Summary of heavy metal analyses and the laboratories where they were performed. EPS = Environmental Protection Service (Vancouver), MOE = British Columbia Environmental Laboratory, NWQ = National Water Quality Laboratory (Burlington), WQB = Water Quality Branch (Vancouver)

Tissue and Analysis	Laboratory
1. Hg analysis:	
Muscle (1980, 1981, 1983)	MOE
Muscle (RL&L)	MOE
Muscle (1980), quality control	WQB
Muscle (1981), quality control	EPS
Muscle (RL&L), quality control	EPS
Muscle (1983), quality control	NWQ
Liver (1980)	EPS
Liver (1981)	MOE
Liver (RL&L)	MOE
Liver (1983)	NWQ
Muscle and Liver (Cominco 1980 & 1984)	Cominco
Sturgeon (1982)	MOE
2. Other Metals:	
Muscle (1980, 1981)	EPS
Muscle (RL&L)	EPS
Muscle (1983)	NWQ
Muscle (1980), quality control	WQB
Liver (1980)	EPS
Liver (1983)	Univ. of Victoria*
Liver (Cominco 1984)	Cominco
Sturgeon (1982)	MOE

*See Part V for methods and results

Table 4

Analytical methods used for Hg determinations
by different laboratories
(abbreviations as in Table 3)

Laboratory	Method	Reference
EPS	Wet digestion in H_2O_2 and H_2SO_4; measurement by cold vapour atomic absorption	Department of Environment/ Department of Fisheries and Oceans 1979
MOE	Wet digestion in H_2SO_4 and HNO_3 measurement using an automated flameless atomic absorption U.V. monitor. Detection limit .05 µg/g	McQuaker 1976
NWQ, WQB	Wet digestion in H_2SO_4, HNO_3 and HCl; followed by oxidation with $KMNO_4$ and $K_2S_2O_8$; excess oxidants reduced by hydroxylamine sulfate measurement by automated sulfate - reduction cold vapour atomic absorption spectrophotometry. Detection limit .01 µg/g	Agemian and Chau 1978
Cominco	Wet digestion in HNO_3; sample refluxed with HCl; measurement on a Hg vapour machine.	J. McCunn, personal communication

Table 5

Analytical methods used by different laboratories for measurements of heavy metals other than Hg (abbreviations as in Table 3)

Laboratory	Method	Reference
EPS	Tissue freeze-dried, then ashed in O_2 plasma; residue digested in HNO_3 + HCl; measurement by plasma emission spectrometry; values converted to wet weight. Low detection limit Cd and Pb measurements by graphite furnace atomic absorption. Moisture content of each sample determined and used to calculate wet weight concentration.	P. Kluckner, personal communication
MOE	Dry digestion in HNO_3 and $HClO_4$; measurement using Applied Research Laboratories Atomic Emmission Spectrometry Inductively Coupled Plasma. Moisture content of each sample determined and used to calculate wet weight concentration.	McQuaker 1976
NWQ, WQB	Wet digestion in HNO_3 and H_2SO_4 in test tubes placed in an aluminum hot block; Cd and Pb concentrated by chelation - solvent extraction using APDC-MIBK; other metals measured direct; measurement by flame atomic absorption spectrophotometry.	Agemian et al. 1980
Cominco	Wet digestion in H_2SO_4, $HClO_4$, HNO_3 and HCl; sample refluxed; measurement by atomic absorption spectrophotometry.	J. McCunn, personal communication

The EPS laboratory measured concentrations of Al, As, Ba, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se, Si, Ti, V and Zn. The detection limits for metals varied depending upon the amount of tissue analyzed.

The National Water Quality laboratory analyzed only for Cd, Cr, Cu, Fe, Mn, Pb, Sr and Zn. Detection limits were not variable.

Detection limits used by the different laboratories are listed in Table 6.

Replicate analyses usually were not performed, but in 1983 the National Water Quality Laboratory studied analytical variability. Seven whole mountain whitefish (Prosopium williamsoni) were homogenized together. The homogenate was divided into seven sub-samples, each of which was analyzed to provide an estimate of variability.

6. Statistical Procedures

Several statistical tests were used to identify trends in the relationships between metal concentrations and size of fish, species of fish, year of collection or site of collection. Most tests were performed separately for each metal in each species.

Pearson product - moment correlations (Sokal and Rohlf 1969) of metal concentration and fish length were calculated. When data were available, correlations with weight and age were also computed.

The data were further analyzed using the BMDP statistical software (Dixon 1983) to perform analyses of variance and covariance and t-tests. Differences in metal concentrations

Table 6

Detection limits for metals in fish tissues.
Values are expressed as μg/g wet weight.
NM = not measured, other abbreviations as in Table 3.

Metal	Detection Limits	
	EPS[1]	NWQ/WQB
Al	.70	NM
As	1.1	NM
Ba	.024	NM
Be	.007	NM
Cd	.010	.02
Co	.11	NM
Cr	.11	.20
Cu		.20
Fe		
Mn	.017	.20
Mo	.20[2]	NM
Ni	.56	NM
Pb	.009	.10
Sb	.56	NM
Se	1.4	NM
Sn	1.4	NM
Sr	.037	.20
Ti	.056	NM
V	.28	NM
Zn		.20

[1] Approximate minimum detectible concentration; limits variable and dependent upon sample weight

[2] 1981 minimum, 1980 minimum was 1.4

among fish species were compared with one-way analyses of variance. For each species, differences in metal concentrations among sites and among years were also compared with 1-way analyses of variance or t-tests. When significant correlations between fish length and metal concentration were observed, analyses of covariance were performed.

Multi-way (factorial) analyses of variance or covariance would have provided more valid tests, if they could have been used with these data. Since no fish species was collected at every site in every year, missing data blocks made the use of factorial tests impossible.

All data were tested for homogeneity of variance using Levene's test (Brown and Forsythe 1974). When this test identified significant heteroscedasticity, the data were reanalyzed using ln-transformations. In most (but not all) cases, transformation removed the heteroscedasticity.

Concentrations of metals which were below detection limits were set at one-half the detection limit for statistical analyses. When variable detection limits were employed, all values less than detection were set at the mean detection limit to avoid introducing variability due to the amount of tissue analyzed. (See section C-5c.)

D. Results and Discussion

Seven species were collected in large enough numbers to be used for detailed analyses. These species were kokanee, largescale sucker, mountain whitefish, northern squawfish (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), rainbow trout and walleye.

Only one individual each of three species, bridgelip sucker (C. columbianus), cutthroat trout (S. clarki) and white sturgeon, was collected. Results for these fish are presented in the Appendices but generally not discussed.

Raw data for all metals detected in all species collected are listed in the Appendices. Results for metals which were below detection limits in all samples analyzed (As, Co, Mo, Ni, Sb, Se and V) are not reported. Results for Al and Ti, which were detectible in only a few samples, are given in the Appendices but not discussed.

Inter- and intralaboratory comparisons of analytical variability are presented in the Appendices. No statistical tests have been performed on these data for two reasons:

1) Intralaboratory replicate analyses were not done on the samples used for interlaboratory comparisons.
2) The samples analyzed by the two laboratories were not identical, since each laboratory analyzed a different part of the same fish rather than a subsample of a tissue homogenate.

Data for all other metals have been analyzed statistically and will be presented in Sections D-1 and D-2 below. Detailed comparisons of Hg, Cd, Cu, Pb and Zn concentrations among species, sites and years have been made. Concentrations of other metals (Ba, Cr, Fe, Mn and Sr) have been compared among species but usually not analyzed further.

All Hg concentrations are reported on a wet weight basis. Other metals data are reported in the Appendices as both wet weight and dry weight concentrations (for laboratories which reported dry weights) but the summary tables presented below (Section D-2) are in wet weight only.

1. Hg

a. Levels in Different Species

Concentration of Hg in muscle tissue varied significantly among fish species. Mercury concentrations were highest in northern squawfish and walleye (Table 7). The maximum Hg concentration detected in any fish species was .91 µg/g measured in a northern squawfish. The highest level measured in a walleye was .55 µg/g. Mercury concentrations in all other fish species were <.3 µg/g, except for .55 µg/g found in a single rainbow trout and .31 µg/g measured in the sturgeon.

Piscivorous fish usually accumulate higher concentrations of mercury than do herbivorous or omnivorous fish (Frank et al. 1978, Potter et al. 1975, Wren et al. 1983). Fish from the Columbia River followed this pattern. As adults both squawfish and walleye consume mainly fish (Scott and Crossman 1973, Carl et al. 1977). Lower Hg concentrations were found in largescale suckers and mountain whitefish which are bottom feeders (Scott and Crossman 1973, Carl et al. 1977), rainbow trout which consume primarily terrestrial insects (R.L. & L. Environmental Services 1982, H. Andrushak, personal communication) and kokanee which feed on mysids, zooplankton and some aquatic insects (R.L. & L. Environmental Services 1982).

Mercury concentrations in Columbia River fish were only moderately elevated by comparison with levels measured in fish from other watersheds. Levels in largescale suckers, mountain whitefish, squawfish, peamouth and rainbow trout were similar to or lower than Hg concentrations reported in the same species from the Fraser River and much lower than levels in fish from the

Table 7

Concentrations of Hg (ug/g wet weight) measured in muscle tissue of fish from the Columbia River.

Species and Year	n	Mean	S. D.	Range
Kokanee, 1981 (RL&L)	15	.06	.049	<.05 - .16
Largescale sucker, 1980	18	.16	.038	.09 - .22
Largescale sucker, 1981	11	.15	.038	.10 - .22
Largescale sucker, 1981 (RL&L)	4	.10	.064	<.05 - .18
Mountain whitefish, 1980	12	.12	.050	<.05 - .21
Mountain whitefish, 1981	11	.16	.067	<.05 - .27
Mountain whitefish, 1981 (RL&L)	10	.13	.045	.09 - .21
Mountain whitefish, 1983	20	.08	.071	<.05 - .22
Northern squawfish, 1980	5	.57	.30	.24 - .86
Northern squawfish, 1981	4	.62	.21	.45 - .91
Northern squawfish, 1981 (RL&L)	8	.48	.163	.32 - .82
Peamouth, 1980	4	.24	.040	.20 - .27
Rainbow trout, 1980	2	.10	.10	<.05 - .17
Rainbow trout, 1980 (Cominco)	30	.07	.097	.01 - .55
Rainbow trout, 1981	1	.12	-	-
Rainbow trout, 1983	15	.04	.023	<.05 - .10
Walleye, 1980	3	.21	.047	.16 - .25
Walleye, 1980 (Cominco)	7	.31	.12	.18 - .48
Walleye, 1981	4	.40	.082	.31 - .49
Walleye, 1981 (RL&L)	9	.31	.104	.21 - .55

Pinchi Lake Mercury Fault Zone (Table 8). Mercury levels in walleye collected in 1980 (Table 7) were comparable to the .25-.28 µg/g measured in walleye from two uncontaminated Manitoba lakes (Scott and Armstrong 1972). The highest concentrations found in Columbia River walleye were comparable to levels measured in Lake Powell walleye (Potter et al. 1975) and well below the average .82 µg/g reported in walleye from 303 Quebec drainage basins (Sherbin 1979). Mercury concentrations in Columbia River walleye were an order of magnitude or more below levels in walleye from Clay Lake on Ontario's highly contaminated Wabigoon - English River system (Table 8).

Similar observations have been made about mercury levels in fish from Lake Roosevelt, which is downstream from Cominco in the United States. Mercury concentrations in squawfish and lake whitefish (Coregonus clupeaformis) were slightly above the U.S. national mean for mercury in fish, while concentrations in walleye and yellow perch (Perca flavescens) were not elevated (Beckman et al. 1985).

b. Hg levels and and guidelines for edible fish flesh

The Canadian Food and Drug Directorate has established a guideline of 0.5 µg/g Hg (wet weight) in edible fish flesh. Fifty-three percent of the northern squawfish equalled or exceeded the guideline. The mercury content in walleye approached, and in one individual exceeded, the 0.5 µg/g guideline. The mercury concentration in one rainbow trout also exceeded 0.5 µg/g, but average mercury concentrations were in the .04-.12 µg/g range (Table 7). The second highest mercury level measured in a trout was .17 µg/g. No explanation for the single high value is apparent.

Table 8

Mercury concentations (μg/g wet weight) measured in fish from British Columbia and other Canadian waters.

Species	Fraser River 1972-73[1] (mean &) (range)	Fraser River 1980[2] (mean &) (range)	Pinchi Lake Mercury Fault Zone[3] (mean &) (range)	Other B.C.[3] (range) (of) (means)	Clay Lake, Ontario[5] (range) (of) (means)	Other Canada[4] (range) (of) (means)
Largescale suckers	.32 (.05-.82)	.16 (ND-.50)	2.59 (max. 3.27)	.10-.27	-	-
Mountain whitefish	.10 (.03-.29)	-	.65 (max. 1.5)	.01-.20	-	.02-.14
Northern squawfish	.68 (.06-1.99)	.39 (.11-1.23)	1.30 (1 fish)	.08-.38*	-	-
Peamouth	.31 (.08-1.01)	.22 (.07-.42)	(.41-2.25)	.10-.40	-	-
Rainbow trout	.09 (.02-.31)	.09 (ND-.14)	.40 (.15-.73)	-	-	.02-.47
Walleye	-	-	-	-	4.36-12.1	.07-3.30

[1] Drinnan and Northcote *in* Stancil (1980)

[2] Singleton (1983)

[3] Garrett et al. (1980)

[4] Sherbin (1979)

[5] Parks et al. (1984), range of means, 1970 - 1982

*except Okanagan; mean and range for Okanagan Lake: .94 (.45-1.79)

More data are required before conclusions about the mercury content of white sturgeon can be made. The single individual sampled contained .31 μg/g Hg, which is less than the Food and Drug Directorate guideline but higher than the mercury levels measured in species other than walleye and squawfish. No age or size data for this fish were available.

c. Correlations between Hg and Size

Mercury concentration in muscle tissue was positively correlated ($P<.01$) with length and weight in kokanee, rainbow trout, and mountain whitefish, and with age in mountain whitefish. Thus, mercury concentration increased with fish size in these species. No significant correlation between Hg concentration and length, weight or age could be demonstrated in largescale suckers, northern squawfish or walleye.

Positive correlations between fish size and mercury concentration have been reported for many species, including largescale suckers (Singleton 1983) and walleye (Scott and Armstrong 1972, Phillips et al. 1980), but this relationship may not be consistent in different populations of the same species. For example, Scott and Armstrong (1972) found a range from good to no correlation between length and mercury concentration in walleye populations from several lakes.

d. Hg levels at Different Sites

Mercury concentrations in fish were compared among collection sites. In 1980, only largescale suckers and mountain whitefish were collected in large enough numbers for among-site comparisons. Mercury levels in these fish collected upstream from Cominco (at Birchbank) were not significantly different from levels in fish collected downstream (at Old Trail Bridge or Waneta) (Table 9).

In 1981, no Federal-Provincial collections were made upstream from Trail. However, mercury concentrations in fish collected by R.L. & L. Environmental Services were not significantly different from concentrations in fish from the Federal-Provincial collections when members of the same species taken from the same sites were compared. For this reason, all of the 1981 data were pooled to compare differences in Hg content of fish from three sites: upstream from Trail (near Hugh Keenleyside dam), at the Old Trail Bridge, and at Waneta. In most species, the Hg concentrations were lowest upstream and highest at Trail (Table 9), but the difference was statistically significant only for walleye ($P<.05$).

Since the Cominco effluent is the major known mercury input in the study area, higher mercury concentrations should be expected in fish collected downstream from Cominco than in fish collected upstream, if the fish are resident in the areas where they were caught. However, if fish move from Trail to Birchbank or to the Hugh Keenleyside Dam, no relation between collection site and mercury content of the fish may be apparent.

Little is known of the movements of most fish species in the Columbia River. R.L. and L. Environmental Services (1982) have suggested that juvenile mountain whitefish migrate upstream, but they give no tag-return data to support this observation. There is some suggestion that largescale suckers and squawfish move less than 5 km from their original capture site, but this conclusion is based

Table 9

Concentrations of Hg (ug/g wet weight) measured in muscle tissue of fish collected from different sites on the Columbia River.
In 1980, "Upstream" = Birchbank.
In 1981, "Upstream" = near Hugh Keenleyside Dam.

Species		Upstream	Trail	Waneta
Largescale suckers, 1980	Mean	.16	.16	.16
	S. D.	.032	.038	.048
	Range	.12 - .21	.11 - .22	.09 - .21
	n	5	7	6
Largescale suckers, 1981	Mean	.10	.16	.13
	S. D.	.064	.037	.038
	Range	<.05 - .18	.12 - .22	.10 - .20
	n	4	6	5
Mountain whitefish, 1980	Mean	.11	.14	-
	S. D.	.055	.032	-
	Range	<.05 - .21	.09 - .16	-
	n	8	4	-
Mountain whitefish, 1981	Mean	.11	.17	.15
	S. D.	.026	.032	.069
	Range	.09 - .15	.14 - .22	<.05 - .27
	n	5	5	11
Northern squawfish, 1981	Mean	.53	.56	.51
	S. D.	.17	.12	.24
	Range	.38 - .82	.47 - .64	.32 - .91
	n	5	2	5
Walleye, 1981	Mean	.26	.40	.39
	S. D.	.029	.13	.10
	Range	.21 - .28	.31 - .49	.26 - .55
	n	5	2	6

on recaptures of only two suckers and five squawfish (R.L. & L. Environmental Services 1984, 1985). Some walleye migrate between Lake Roosevelt and the Hugh Keenleyside Dam (Ash et al. 1982, Beckman et al. 1985).

Thus, it is difficult to interpret the results of comparisons of mercury levels in fish from different sites. If the walleye sampled near Hugh Keenleyside Dam had all travelled upstream from Lake Roosevelt, they must have spent at least some time in an environment which receives mercury inputs. Therefore, walleye collected upstream from Trail should not have contained lower mercury levels than walleye collected downstream, unless they had passed through the area affected by effluents so quickly that they had not accumulated much mercury or unless they had been in an environment not affected by mercury discharges long enough to have eliminated a significant portion of the mercury they had accumulated. No information on residency times of walleye in the river is available, but there have been suggestions that some walleye are residents in the study area (H. Andrushak, personal communication) and that a few walleye may be spawning in the Columbia upstream from Trail (R.L. & L. Environmental Services 1984, 1985).

Mercury concentrations in the kokanee from Deer Creek and Norns Creek were compared (see Appendices XIII and XIV). The Hg concentration of every fish from Deer Creek was below the detection limit (.05 µg/g), while Hg was measurable in all fish from Norns Creek. However, analysis of covariance (using length as the covariate) did not show any significant difference in Hg concentrations between these sites.

The kokanee which spawn in Deer Creek are residents of Lower Arrow Lake, above the Hugh Keenleyside Dam, while the fish which spawn in Norns Creek are migrants from Lake Roosevelt (R.L. & L. Environmental Services 1982). Thus, higher mercury levels are expected in the Norns Creek fish, which have spent part of their lives downstream from Cominco.

Comparison of mercury levels in the two kokanee populations was difficult because the fish from Deer Creek were all smaller than the fish from Norns Creek. Analysis of covariance extrapolates the mercury-length regression and assumes that the same regression fits both populations. Moriarty et al. (1984) have warned that such extrapolation can introduce errors which may make the covariance analysis invalid.

e. Hg levels in Different Years

Mercury concentrations in the various species were compared among years. The only significant difference found was for walleye, in which the Hg concentration was higher in 1981 than in 1980 ($P<.05$).

This apparent difference might be the result of small sample size. Cominco's walleye data were not included in the statistical test because the mercury was measured by a different analytical technique, but the mercury levels measured in 1980 by Cominco were similar to the 1981 levels (Table 7).

Mercury levels in largescale suckers and mountain whitefish appeared somewhat higher than concentations measured in these species in 1976. The mean .11 (range .05-.20) µg/g found in suckers and the .07 (range .05 -

.10) μg/g found in mountain whitefish caught downstream from Cominco in 1976 (B.C. Ministry of Environment 1979) were higher than concentrations measured in these species caught at Trail and Waneta in 1980 and 1981 (Table 9). No walleye data from the earlier study were available for comparison.

f. Hg in Livers

Usually there was not enough replication for statistical tests to be performed on Hg measurements in liver. The one statistical test which was done, an analysis of variance comparing Hg concentrations in the different species collected in 1981 (Appendices X and XV), did not show any significant differences. In 1980, the livers of largescale suckers collected from Birchbank, Trail and Waneta were analyzed. Mercury concentration in livers of suckers from Trail appeared highest, while the level in suckers from Birchbank appeared lowest (Table 10) but since there was no replication, statistical comparison was not possible.

If fish move among sampling sites, mercury levels in liver may be more closely related to mercury levels at the collection site than are concentrations in muscle. Any change in the rate of mercury accumulation or elimination should be observed in liver before it is seen in muscle because of the higher metabolic rate of liver (Jernelov and Lann 1971).

g. Cominco's Monitoring Results

Data from Cominco's monitoring program were analysed separately and the following observations were made:

1) Mercury concentrations in rainbow trout collected "above Cominco" were not significantly different from Hg

Table 10

Concentrations of Hg (ug/g wet wt) measured in liver composites from fish collected in May, 1980. Values in parentheses indicate number of fish in composite.

Species and Collection Site	Hg
Birchbank:	
Largescale sucker (5)	.06
Mountain whitefish (7)	.27
Northern squawfish (1)	.79
Rainbow trout (1)	.14
Trail:	
Largescale sucker (7)	.19
Mountain whitefish (4)	.30
Peamouth (2)	.19
Rainbow trout (1)	.15
Walleye (1)	.28
Waneta:	
Largescale sucker (6)	.15
Northern squawfish (4)	.45
Peamouth (2)	.05
Walleye (2)	.41

concentrations in trout collected "below Cominco". It is not clear where these sampling sites were located, and it is possible that trout moved between the two sites. Most trout tagged by R.L. & L. Environmental Services (1984, 1985) were recaptured within 10 km of their original tagging location, but some individuals had moved 15-46 km.

2) The Hg concentrations in liver and muscle of rainbow trout were highly correlated (r=.78, P<.01). The mean Hg concentration in liver was .22 µg/g, in muscle .07 µg/g.

3) There was no significant correlation between the Hg concentrations of liver and muscle in walleye (r=.05, P>.10).

4) The mean Hg concentration in walleye liver in 1984 (.08 µg/g) was significantly (P<.01) lower than in 1980 (.64 µg/g). A decrease in the mercury concentration of walleye muscle (which was not analysed in 1984) cannot be inferred from this result, since there was no correlation between the mercury concentrations of liver and muscle in 1980.

2. Other Metals

a. Levels in Different Species

Means and ranges of concentrations of all metals in muscle tissue of all species are summarized in Tables 11 and 12.

Concentrations of most heavy metals in muscle tissue varied significantly (P<.05) among species. The highest concentration of Cu was measured in kokanee. The highest concentrations of Pb and Zn were found in largescale suckers and peamouth, with similar levels of Zn also measured in kokanee. Mountain whitefish and kokanee contained the highest concentrations of Fe. The highest levels of Ba, Mn and Sr were found in largescale

Table 11

Concentrations of Cd, Cu, Pb and Zn measured in muscle tissue of fish collected from the Columbia River. Values are reported as ug/g wet weight.

Species and Year		Cd	Cu	Pb	Zn
Kokanee, 1981	Mean	<.0097	1.4	.026	8.7
(R. L. & L.)	S. D.	0	.41	.029	2.7
	Range	<.0087 - <.011	.77 - 2.1	<.010 - .12	5.3 - 13.7
	n	15	15	15	15
Largescale sucker, 1980	Mean	.03	1.1	.49	8.2
	S. D.	.028	.91	.46	2.5
	Range	<.010 -.11	.52 - 4.5	.042 - 1.6	5.3 - 15.
	n	18	18	18	18
Largescale sucker, 1981	Mean	.009	.96	.40	9.1
	S. D.	.006	.30	.35	2.7
	Range	<.01 -.02	.61 - 1.6	.070 - 1.2	5.2 - 15.
	n	11	11	11	11
Largescale sucker, 1981	Mean	<.0091	.62	.087	6.5
(R. L. & L.)	S. D.	0	.091	.033	.35
	Range	<.0085 - .0099	.54 - .75	.052 - .12	6.1 - 6.9
	n	4	4	4	4
Mountain whitefish, 1980	Mean	.019	.94	.12	4.9
	S. D.	.017	.28	.12	.94
	Range	<.011 -.051	.62 - 1.6	<.014 - .36	4.0 - 6.5
	n	11	11	11	11
Mountain whitefish, 1981	Mean	.018	1.1	.15	4.8
	S. D.	.014	.45	.15	.87
	Range	<.01 -.053	.74 - 2.3	.026 - .53	3.8 - 6.2
	n	11	11	11	11
Mountain whitefish, 1981	Mean	.006	.77	.068	4.8
(R. L. & L.)	S. D.	.003	.20	.064	.68
	Range	<.013 - .015	.48 - 1.2	<.013 - .18	3.6 - 6.2
	n	10	10	10	10
Mountain whitefish, 1983	Mean	.02	.45	.1	5.8
	S. D.	.026	.15	.09	1.2
	Range	<.02 - .10	.23 - .66	<.1 - .3	3.6 - 8.0
	n	13	12	13	13

Table 11 (Cont'd)

Species and Year		Cd	Cu	Pb	Zn
Northern squawfish, 1980	Mean	.015	1.3	.041	5.4
	S. D.	.004	1.1	.040	1.3
	Range	.012 -.020	.62 - 3.3	<.011 - .11	3.7 - 7.2
	n	5	5	5	5
Northern squawfish, 1981	Mean	.019	1.1	.12	5.8
	S. D.	.018	.44	.056	1.1
	Range	<.01 -.044	.63 - 1.7	.074 - .20	4.8 - 6.9
	n	4	4	4	4
Northern squawfish, 1981 (R. L. & L.)	Mean	<.0096	1.0	.068	5.1
	S. D.	0	.44	.056	.76
	Range	<.0085 - <.011	.51 - 1.7	<.009 - .15	3.6 - 5.9
	n	8	8	8	8
Peamouth, 1980	Mean	.030	1.7	.27	8.3
	S. D.	.018	1.6	.32	1.1
	Range	.011 - .055	.53 - 4.0	.071 - .74	7.4 - 10
	n	4	4	4	4
Rainbow trout, 1980	Mean	.065	1.4	.27	5.4
	S. D.	-	-	-	-
	Range	-	-	-	-
	n	1	1	1	1
Rainbow trout, 1981	Mean	.02	.89	.058	5.6
	S. D.	-	-	-	-
	Range	-	-	-	-
	n	1	1	1	1
Rainbow trout, 1983	Mean	<.02	.59	<.1	6.3
	S. D.	0	.17	.05	1.7
	Range	<.02 - <.02	.29 - .82	<.1 - .2	3.6 - 9.7
	n	15	15	15	15
Walleye, 1980	Mean	.017	.69	.026	4.6
	S. D.	.013	.12	.034	.17
	Range	<.010 -.030	.56 - .79	<.010 - .065	4.5 - 4.8
	n	3	3	3	3

Table 11 (Cont'd)

Species and Year		Cd	Cu	Pb	Zn
Walleye, 1981	Mean	.006	.72	.016	5.5
	S. D.	.002	.15	.007	.53
	Range	<.01 -.01	.52 - .86	.010 - .022	5.0 - 6.1
	n	4	4	4	4
Walleye, 1981 (R. L. & L.)	Mean	<.010	.99	.039	4.8
	S. D.	0	.57	.011	.78
	Range	<.0092 - <.012	.40 - 1.9	.022 - .060	4.0 - 6.3
	n	9	9	9	9

Table 12

Concentrations of other metals measured in muscle tissue of fish collected from the Columbia River. Values are reported as ug/g wet weight.

Species and Year		Ba	Cr	Fe	Mn	Sr
Kokanee, 1981 (R. L. & L.)	Mean	.046	.15	6.1	.061	.31
	S. D.	.031	.044	2.5	.036	.19
	Range	<.026 - .098	<.11 - .21	2.7 - 12	<.017 - .12	.044 - .60
	n	15	15	15	15	15
Largescale sucker, 1980	Mean	.023	.36	3.5	.44	.46
	S. D.	.012	.37	1.0	.21	.17
	Range	<.027 - .056	<.16 - 1.6	1.8 - 5.6	.20 - 1.2	.26 - .83
	n	18	18	18	18	18
Largescale sucker, 1981	Mean	.074	.25	5.8	.34	.42
	S. D.	.021	.13	1.4	.10	.11
	Range	.038 - .11	<.16 - .59	4.0 - 8.9	.20 - .59	.26 - .58
	n	11	11	11	11	11
Largescale sucker, 1981 (R. L. & L.)	Mean	.055	.10	2.7	.26	.35
	S. D.	.009	.037	.81	.041	.088
	Range	.044 - .065	<.13 - .16	2.0 - 3.9	.23 - .32	.23 - .43
	n	4	4	4	4	4
Mountain whitefish, 1980	Mean	<.041	2.0	6.3	.15	.20
	S. D.	0	2.8	2.8	.025	.098
	Range	<.034 - <.045	<.17 - 9.5	2.9 - 11.	.13 - .21	.076 - .33
	n	11	11	11	11	11
Mountain whitefish, 1981	Mean	.023	.21	15	.095	.24
	S. D.	.01	.086	8	.035	.11
	Range	<.024 - .045	<.16 - .33	4.8 - 33.	.045 - .16	.10 - .44
	n	11	11	11	11	11
Mountain whitefish, 1981 (R. L. &. L.)	Mean	<.039	<.20	5.7	.051	.17
	S. D.	0	0	2.5	.06	.14
	Range	<.033 - <.041	<.17 - <.21	3.0 - 9.1	<.026 - .21	.056 - .51
	n	10	10	10	10	10
Mountain whitefish, 1983	Mean	-	<.20	8.5	.13	.3
	S. D.	-	0	3.1	.049	.24
	Range	-	<.20 - <.20	3.9 - 12.7	<.2 - .2	<.2 - .9
	n	-	12	12	12	13

Table 12 (Cont'd)

Species and Year		Ba	Cr	Fe	Mn	Sr
Northern squawfish, 1980	Mean	.046	.43	4.2	.19	.56
	S. D.	.039	.12	.77	.014	.21
	Range	<.032 - .094	.28 - .58	3.2 - 5.0	.17 - .21	.35 - .90
	n	5	5	5	5	5
Northern squawfish, 1981	Mean	.29	.22	7.5	.13	.34
	S. D.	.23	.053	3.0	.034	.15
	Range	.12 - .63	.17 - .29	3.6 - 11.	.093 - .17	.22 - .55
	n	4	4	4	4	4
Northern squawfish, 1981 (R. L. &. L)	Mean	.096	.16	4.8	.073	.30
	S. D.	.056	.056	4.3	.037	.06
	Range	.046 - .20	<.15 - .25	1.8 - 15.	.035 - .15	.22 - .41
	n	8	8	8	8	8
Peamouth, 1980	Mean	.13	.20	5.3	.20	.59
	S. D.	.13	.13	.71	.031	.28
	Range	.038 - .31	<.14 - .32	4.7 - 6.3	.17 - .24	.40 - 1.0
	n	4	4	4	4	4
Rainbow trout, 1980	Mean	<.041	.24	5.9	.11	.39
	S. D.	-	-	-	-	-
	Range	-	-	-	-	-
	n	1	1	1	1	1
Rainbow trout, 1981	Mean	<.028	.16	5.01	<.019	.08
	S. D.	-	-	-	-	-
	Range	-	-	-	-	-
	n	1	1	1	1	1
Rainbow trout, 1983	Mean	-	<.20	4.6	<.2	.2
	S. D.	-	0	1.7	0	.15
	Range	-	<.20 - <.20	2.2 - 7.3	<.2 - <.2	<.2 - .5
	n	-	15	15	15	15
Walleye, 1980	Mean	<.031	.44	2.6	.13	.12
	S. D.	0	.25	1.5	.01	.061
	Range	<.030 - <.031	.25 - .72	1.7 - 4.4	.12 - .14	.045 - .16
	n	3	3	3	3	3

Table 12 (Cont'd)

Species and Year		Ba	Cr	Fe	Mn	Sr
Walleye, 1981	Mean	.029	.19	5.3	.045	.088
	S. D.	.023	.08	1.8	.045	.054
	Range	<.029 - .064	<.16 - .28	3.4 - 7.7	<.020 - .11	<.040 - .15
	n	4	4	4	4	4
Walleye, 1981 (R. L. & L.)	Mean	<.031	.19	2.1	.041	.054
	S. D.	0	.053	.62	.018	.026
	Range	<.028 - <.034	<.17 - .26	1.4 - 3.6	.027 - .080	<.037 - .10
	n	9	9	9	9	9

suckers; Sr concentrations were also high in northern squawfish. Walleye contained particularly low levels of Ba, Fe, Pb, Sr and Zn. Concentrations of Cd and Cr did not differ significantly among species.

Many authors have observed that concentrations of metals including Cd, Cr, Cu, Mn, Pb and Zn are higher in omnivorous or bottom-feeding fish than in predators or fish that feed in the water column (Mathis and Cummings 1973, Badsha and Goldspink 1982, Salanki et al. 1982, Ney and Van Hassel 1983, Czarnezki 1985). Thus, it is not surprising that suckers contained particularly high concentrations and walleye contained particularly low concentrations of most metals.

b. Comparison of Metal Levels with Other Reported Values

All values reported in this section are for muscle tissue, unless otherwise noted.

1) Cd

Cadmium concentrations in muscle of Columbia River fish were similar to or lower than most Cd levels reported in muscle of fish from other watersheds (Table 13). Cadmium concentrations in most rainbow trout and walleye (Table 11) were in the ranges reported in trout (.013-.027 μg/g) and walleye (<.01-.064 μg/g) from several New York State waters (Lovett et al. 1972). A much higher mean Cd level, .51 μg/g, was found in rainbow trout from the American Falls Reservoir, Idaho (Kent and Johnson 1979).

Although the Cd levels in muscles of Columbia River fish were not particularly high, elevated Cd levels in whole fish have been reported for Lake

Roosevelt. Concentrations measured in 1976-1977 were above the 85th percentile for fish from 98 U.S. monitoring stations (May and McKinney 1981). Cadmium concentrations measured in 1982 were higher than the U.S. national average (Beckman et al. 1985).

Lake Roosevelt receives Cd inputs from several sources other than Cominco including mining, smelting and industrial effluents on the Coeur d'Alene-Spokane River (May and McKinney 1981), which may explain the elevated Cd concentrations there. Comparison of Columbia River muscle data with whole fish data may also be misleading. Although muscle Cd levels were low, Cd concentrations in the livers of Columbia River fish were higher than levels in fish from other areas. (See Section D-2-e.)

ii. Cu

Copper concentrations in Columbia River fish were similar to or higher than levels measured in the same species from the Fraser River (Table 14). Likewise, these levels were similar to or higher than Cu concentrations measured in fish from other watersheds (Table 13).

Copper levels measured in fish in Lake Roosevelt were lower than the overall mean concentration in fish from the U.S. National Pesticides Monitoring Program (Beckman et al. 1985).

iii. Pb

Average Pb levels in Columbia River fish were generally lower than lead levels in fish from waters receiving domestic and industrial effluents and

Table 13
Ranges of mean metal concentrations (μg/g) measured in muscles of various fish species from different waters.

Location	Cd	Cu	Pb	Zn	Reference
Columbia River[1]	<.02-.03	.45-1.7	.016-.49	4.6-9.1	This Study
Columbia River[2]	.03-.13	3.2-7.1	.075-2.2	17-43	
Moose Lake, Man.[1]	<.05	.50-.70	<.5	14-19	Uthe and Bligh 1971
Great Lakes Basin[1]	<.05	.70-1.28	<.5	11-20	
Baie du Doré,[1,3] Lake Huron	.06	.45	.19	4.69	Brown and Chow 1977
Toronto Harbour[1,3]	.13	1.93	1.78	36.02	
Illinois River[1] (downstream from Chicago)	.03	.13-.21	.57-.64	3.49-5.02	Mathis and Cummings 1973
Tadenac Lake,[1] Ontario	ND-.22	.8-1.9	ND-1.9	6.7-60.2	Wren et al. 1983
Lake Balaton,[2] Hungary	.57-.65	1.72-3.12	3.59-4.86	39.4-64.3	Salanki et al. 1982
"A highly organic softwater pond"[2]	-	.29-1.08	-	12.7-31.7	Weiner and Geisy 1979

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[1] Wet weight

[2] Dry weight

[3] Mean over all species collected

Table 14
Means and ranges of metal concentrations (μg/g wet weight) measured in muscles of various fish species from the Columbia and Fraser Rivers

Species	Metal	Columbia[1]	Fraser 1972-73[2]	Fraser 1980[3]
Largescale sucker	Cu	.96-1.1	.46(.10-1.00)	.31(ND-.78)
	Zn	8.2-9.1	6.17(3.12-15.02)	5.32(1.91-10.8)
Mountain whitefish	Cu	.45-1.1	.61(.38-.85)	-
	Zn	4.8-5.8	4.79(3.41-7.20)	-
Northern squawfish	Cu	1.1-1.3	.60(.12-1.70)	.36(ND-3.46)
	Zn	5.4-5.8	6.49(3.27-16.07)	4.64(ND-8.56)
Peamouth	Cu	1.7	.75(.17-2.42)	.34(ND-.60)
	Zn	8.3	9.68(3.81-29.25)	6.81(3.59-33.0)
Rainbow trout	Cu	.59	.63(.22-1.00)	.65(ND-1.08)
	Zn	6.3	4.93(3.20-9.21)	4.83(3.92-6.05)

[1] This study, range of annual means (from Table 11)

[2] Drinnan and Northcote *in* Stancil 1980

[3] Singleton 1983

lower than the mean concentrations in two species from remote Tadenac Lake (Table 13). Nevertheless, lead levels in some largescale suckers, especially those caught downstream from Cominco (Table 17) were elevated. The highest levels were in excess of 1.0 µg/g, well above the .030-.300 µg/g range measured in a survey of 12 fish species from Ontario lakes and rivers (Chau et al. 1980), and comparable to the lead levels measured in several species of suckers collected to assess a spill from a lead mine tailings pond (Czarnezki 1985).

Lead levels in fish from Lake Roosevelt were also elevated. In 1976-77, the Pb concentration in largescale suckers was in excess of the 85th percentile for lead in whole fish from U.S. waters (May and McKinney, 1981). In 1982, the mean Pb concentration for all species sampled was more than twice the U.S. national average (Beckman et al. 1985). Since Lake Roosevelt receives Pb inputs from mining, smelting and industrial activities on the Coeur d'Alene - Spokane River (May and McKinney 1981), elevated Pb levels cannot be attributed entirely to Canadian sources.

iv. Zn

Zinc concentrations in Columbia River fish were similar to levels in the same species from the Fraser River (Table 14). These levels were equal to or lower than zinc concentrations in fish from other watersheds (Table 13).

v. Other Metals

Concentrations of other metals in fish tissues have infrequently been documented.

Levels of Cr in Columbia River fish were usually somewhat higher than Cr concentrations in fish from other areas. Mean Cr concentrations in Columbia River species ranged from <.2-.43 µg/g, except for an average 2.0 µg/g found in mountain whitefish in 1980 (Table 12). These levels were similar to mean concentrations found in the same species from the Fraser River (Singleton 1983), but the maximum concentration found in a Columbia largescale sucker was almost four times the maximum .42 µg/g measured in a sucker from the Fraser. In the Illinois River, average Cr concentrations were .12 µg/g in carnivores and .22 µg/g in omnivores (Mathis and Cummings 1973). Chromium concentrations in pike and white suckers from the Hudson's Bay lowlands ranged from undetectable to .47 µg/g, but only one fish (a sucker) contained more than .28 µg Cr/g (McCrea et al. 1984). Chromium concentrations reported by Uthe and Bligh (1971) for fish from the Great Lakes Basin were an order of magnitude below these levels.

Concentrations of Mn in Columbia River fish (Table 12) were similar to other recorded values. Singleton (1983) reported a range of average Mn concentrations in Fraser River fish from undetectable in rainbow trout to .27 µg/g in largescale suckers. Uthe and Bligh (1971) found a range of Mn concentrations of .02-3.16 µg/g in fish from the Great Lakes Basin and Moose Lake, Manitoba. In Tadenac Lake, Ontario, Wren et al. (1983) found average Mn concentrations ranging from 0.7-1.2 µg/g in four species and a much higher Mn level, 20.6 µg/g, in a fifth species, the bluntnose minnow (Pimphales notatus). Weiner and Giesy (1979) reported dry weight Mn concentrations of .32-1.21 µg/g in fish from a softwater pond, which is comparable to the .20-2.0 µg/g dry weight range measured in Columbia River fish.

Average Fe concentrations in Columbia River fish (Table 12) were similar to the mean 3.99-7.19 µg/g, measured by Singleton (1983). Mean Fe concentrations in Tadenac Lake were within the same range for all species except bluntnose minnows, whose average Fe content of 109.6 µg/g (Wren et al. 1983) was an order of magnitude higher than most values measured in Columbia River fish.

Only one study has included measurements of Ba and Sr which can be compared with levels of these metals in Columbia River fish. Both metals were undetectable in most Tadenac Lake species (Wren et al. 1983), but the detection limits (0.4 µg/g for both metals) were higher than values measured in most Columbia River fish. The 8.0 µg/g Ba and 9.1 µg/g Sr measured in bluntnose minnows were at least an order of magnitude higher than concentrations of these metals in any Columbia River species (Table 12).

c. Metal Levels and Guidelines for Edible Fish Flesh

Since the Canadian Food and Drug Directorate is now using site-specific assessments to predict human health risks from metal levels in fish, there are no current guidelines with which to compare metal levels in Columbia River fish. In order to evaluate these levels, the concentrations are compared with guidelines which have been used previously. Both Uthe and Bligh (1971) and the

B.C. Ministry of Environment (1979) assessed health risks using the Food and Drug Directorate tolerance limit of 100 µg/g (wet weight) for both Cu and Zn (Canada Department of National Health and Welfare, 1968). Since no guideline for Cd concentration in fish was available, the B.C. Ministry of Environment (1979) and Singleton (1983) used the tolerance limit for Cd in meat of livestock, .2 µg/g (wet weight). The most recent Food and Drug tolerance limit was 0.5 µg/g wet weight for Pb in "fish protein" which Singleton (1983) used as being equivalent to Pb in edible flesh.

Levels of all metals except lead were lower than the historical guidelines described above. Average Pb concentrations in largescale suckers collected downstream from Cominco (Tables 17) were greater than 0.5 µg/g. Lead levels in some suckers and in the single sturgeon analyzed were in excess of 1.0 µg/g. Fifty-eight percent of the largescale suckers and 15% of the mountain whitefish collected downstream from Cominco had Pb concentrations equal to or greater than 0.3 µg/g.

Since there are no current Canadian guidelines for Pb in fish, and since Pb levels in some Columbia River fish exceed Pb levels recommended in published literature (Czarnezki 1985), a Food and Drug Directorate assessment of Pb in Columbia River fish is desirable.

d. Metal Levels at Different Sites

Results of among-site comparisons of metal levels in Columbia River fish must be interpreted with caution because of inadequate knowledge of the movement patterns of the fish (See discussion, Section D-1-d).

Concentrations of Cd, Cu, Pb and Zn in fish muscle were compared among sites. In 1980, only largescale suckers and mountain whitefish were collected in large enough numbers to be used for these comparisons. Metal levels in suckers from three sites, Birchbank, Trail and Waneta, were compared. Since no whitefish were obtained at Waneta in 1980, metal levels at Birchbank and Trail were compared. The 1981 Federal-Provincial and R. L. & L. Environmental Services data were pooled as described previously (Section D-1), and metal levels in muscle of largescale suckers, mountain whitefish, northern squawfish and walleye were compared among the three sites, upstream near Hugh Keenleyside Dam, Trail and Waneta. Results of these comparisons are summarized in Tables 15-18.

Concentrations of all four metals generally were lower in fish collected upstream from Trail than in fish collected at Trail or Waneta.

Cadmium concentrations in whitefish were significantly lower ($P<.01$) in fish collected upstream from Trail than in fish collected downstream in both 1980 and 1981. No significant differences in Cd concentrations among sites could be demonstrated for any other species, but in 1981 the only detectable Cd concentrations in squawfish and walleye were found in fish from Trail.

Copper concentrations were significantly lower ($P<.05$) in suckers collected at the upstream site than in suckers collected at Waneta in 1981. That year Cu concentrations were also lower ($P<.01$) in squawfish collected at the upstream site.

Table 15

Concentrations of Cd measured in muscle tissue of fish collected from three sites on the Columbia River. Values are reported as ug/g wet weight.
In 1980 Upstream = Birchbank.
In 1981 Upstream = near Hugh Keenleyside Dam.

Species		Upstream	Trail	Waneta
Largescale sucker 1980	Mean	.021	.043	.023
	S. D.	.022	.033	.023
	Range	<.010 - .058	.014 - .11	.012 - .070
	n	5	7	6
Largescale sucker 1981	Mean	<.0091	.007	.012
	S. D.	0	.003	.008
	Range	<.0085 - <.0099	<.01 - .01	<.01 - .02
	n	4	6	5
Mountain whitefish 1980	Mean	.0076	.038	-
	S. D.	.0068	.010	-
	Range	<.011 - .023	.026 - .051	-
	n	7	4	-
Mountain whitefish 1981	Mean	<.014	.023	.011
	S. D.	0	.018	.008
	Range	<.013 - <.014	.010 - .053	<.01 - .025
	n	5	5	11
Northern squawfish 1981	Mean	<.0092	.032	<.010
	S. D.	0	.016	0
	Range	<.0085 - <.010	.021 - .044	<.0098 - <.011
	n	5	2	5
Walleye 1981	Mean	<.011	.007	<.010
	S. D.	0	.004	0
	Range	<.0095 - <.012	<.01 - .01	<.0092 - <.011
	n	5	2	6

Table 16

Concentrations of Cu measured in muscle tissue of fish collected from three sites on the Columbia River.
Values are reported as ug/g wet weight.
In 1980 Upstream = Birchbank.
In 1981 Upstream = near Hugh Keenleyside Dam.

Species		Upstream	Trail	Waneta
Largescale sucker	Mean	1.6	.82	.95
1980	S. D.	1.6	.35	.38
	Range	.52 - 4.5	.52 - 1.6	.57 - 1.5
	n	5	7	6
Largescale sucker	Mean	.62	.83	1.1
1981	S. D.	.091	.26	.29
	Range	.54 - .75	.61 - 1.3	.80 - 1.6
	n	4	6	5
Mountain whitefish	Mean	.99	.84	-
1980	S. D.	.33	.12	-
	Range	.62 - 1.6	.72 - .96	-
	n	7	4	-
Mountain whitefish	Mean	.72	.93	1.1
1981	S. D.	.21	.23	.47
	Range	.48 - .99	.74 - 1.2	.68 - 2.3
	n	5	5	11
Northern squawfish	Mean	.73	.81	1.5
1981	S. D.	.27	.26	.20
	Range	.51 - 1.2	.63 - .99	1.2 - 1.7
	n	5	2	5
Walleye	Mean	1.2	.66	.79
1981	S. D.	.68	.19	.29
	Range	.41 - 1.9	.52 - .79	.40 - 1.1
	n	5	2	6

Table 17

Concentrations of Pb measured in muscle tissue of fish collected from three sites on the Columbia River.
Values are reported as ug/g wet weight.
In 1980 Upstream = Birchbank.
In 1981 Upstream = near Hugh Keenleyside Dam.

Species		Upstream	Trail	Waneta
Largescale sucker 1980	Mean	.17	.78	.41
	S. D.	.036	.61	.23
	Range	.12 - .22	.042 - 1.6	.25 - .84
	n	5	7	6
Largescale sucker 1981	Mean	.087	.61	.14
	S. D.	.033	.36	.055
	Range	.052 - .12	.26 - 1.2	.070 - .19
	n	4	6	5
Mountain whitefish 1980	Mean	.074	.21	-
	S. D.	.069	.15	-
	Range	<.014 - .18	.069 - .36	-
	n	7	4	-
Mountain whitefish 1981	Mean	.046	.20	.10
	S. D.	.076	.20	.073
	Range	<.013 - .18	.026 - .53	.043 - .30
	n	5	5	11
Northern squawfish 1981	Mean	.034	.15	.11
	S. D.	.033	.078	.03
	Range	<.009 - .088	.090 - .20	.074 - .15
	n	5	2	5
Walleye 1981	Mean	.041	.016	.030
	S. D.	.014	.008	.013
	Range	.022 - .060	.010 - .022	.010 - .048
	n	5	2	6

Table 18

Concentrations of Zn measured in muscle tissue of fish collected from three sites on the Columbia River.
Values are reported as ug/g wet weight.
In 1980 Upstream = Birchbank.
In 1981 Upstream = near Hugh Keenleyside Dam.

Species		Upstream	Trail	Waneta
Largescale sucker 1980	Mean	6.5	8.3	9.5
	S. D.	.89	3.4	1.1
	Range	5.3 - 7.5	5.6 - 15.	8.2 - 11.
	n	5	7	6
Largescale sucker 1981	Mean	6.5	8.8	9.5
	S. D.	.35	3.6	1.4
	Range	6.1 - 6.9	5.2 - 15.	7.5 - 11.
	n	4	6	5
Mountain whitefish 1980	Mean	4.3	5.9	-
	S. D.	.47	.60	-
	Range	4.0 - 5.3	5.3 - 6.5	-
	n	7	4	-
Mountain whitefish 1981	Mean	4.8	4.6	4.9
	S. D.	.31	.64	.97
	Range	4.5 - 5.3	3.8 - 5.3	3.6 - 6.2
	n	5	5	11
Northern squawfish 1981	Mean	5.3	5.7	5.2
	S. D.	.52	1.1	1.2
	Range	4.6 - 5.9	5.0 - 6.5	3.6 - 6.9
	n	5	2	5
Walleye 1981	Mean	5.1	5.0	4.9
	S. D.	.87	.007	.89
	Range	4.0 - 6.3	5.02 - 5.03	4.0 - 6.1
	n	5	2	6

Lead concentrations in suckers varied significantly ($P<.05$) among sites in both years, with lowest levels measured upstream and highest levels measured at Trail. Lead concentrations were also significantly lower ($P<.05$) in squawfish collected at the upstream site than in squawfish collected at Trail or Waneta in 1981.

Zinc levels were significantly ($P<.01$) lower in whitefish from Birchbank than in whitefish from Trail in 1980. Zinc concentrations did not differ significantly among sites for any other species.

The pattern of lowest metal levels in fish collected upstream from Trail and highest metal levels in fish collected at Trail suggest that concentrations of metals in fish muscle are correlated with environmental levels, but this observation was not true for all metals in all species. Conflicting reports of the relationships between metal concentrations in fish muscle and environmental levels appear in the literature. Wilson et al. (1981) found no relation between environmental levels and concentrations of Cd, Cu and Zn in muscle of rainbow trout collected above and below acid mine drainage. On the other hand, Murphy et al. (1979) found significantly higher Cd and Zn levels in muscle of largemouth bass (Micropterus salmoides) and bluegills (Lepomis macrochirus) from an area of a lake receiving industrial effluent than in those from an area isolated from the effluent.

Concentrations of all metals in the kokanee from Deer Creek were compared with concentrations in the kokanee from Norns Creek. Levels of Cu, Zn, Ba, Mn and Sr were significantly higher ($P<.01$) in the Deer Creek samples

(Appendices XIII and XVI). These differences may reflect differences in the environments of the two populations, but little information on levels of these metals in Deer Creek and Norns Creek is available to support this assumption.

It is rather surprising that Cu and Zn levels were higher in the Deer Creek kokanee, which come from Lower Arrow Lake, than in the Norns Creek fish, which come from Lake Roosevelt (See discussion, Section D-1-d). The B.C. Ministry of Environment also observed higher Cu and Zn levels in this species and rainbow trout from Lower Arrow Lake than in kokanee and trout caught downstream from Cominco. This paradox may occur because Cu and Zn are metabolically regulated, and therefore tissue concentrations may be independent of environmental levels in at least some species (Gächter and Geiger 1979, Wiener and Giesey 1979). The higher Cu and Zn levels in Lower Arrow Lake fish could also be explained by differences in water chemistry if the metals in the reservoir occurred in more bioavailable forms.

e. Metal Levels in Different Years

Concentrations of Cd, Cu, Pb and Zn measured in muscle tissue of the various species in 1980 and in 1981 were compared.

Cadmium concentrations in suckers were lower ($P<.05$) in 1981 than in 1980. This observation may represent a trend toward lower Cd levels. Cadmium concentrations measured in largescale suckers, rainbow trout and kokanee in 1975 were in excess of 0.2 µg/g (B.C. Ministry of Environment 1977). Cadmium concentrations measured in the species in 1976 were below 0.2 µg/g, except in one sucker (B.C. Ministry of Environment 1979).

No other differences in metal levels in any species were observed. Meaningful comparisons with metal concentrations measured in 1983 could not be made as the chemical analyses were performed by a different laboratory using a different analytical technique.

f. Metals in Livers

Since there was no replication in the 1980 liver data (Table 19), it could not be used for statistical comparisons, but some general observations can be made. Metal levels were higher in liver than in muscle tissue. This difference was especially pronounced for Cd, which was undetectable in many of the muscle samples. Concentrations of metals, particularly Cd, Cu and Zn, are usually higher in liver than in muscle (Brown and Chow 1977, Holcombe et al. 1979, Wiener and Geisy 1979, Salanki et al. 1982). Less than 11% of the body burden of Cd and Zn was contained in muscle of bluegill and bass (Murphy et al. 1979). Between 9% and 46% of the body burden of Cd was found in liver of Cottus gobio (Moriarty et al. 1984).

Metal concentrations in livers of Columbia River fish, especially fish collected downstream from Trail, were higher than metal levels in livers of fish from most other areas (Table 20). Metal concentrations in walleye livers measured by Cominco in 1984 were much higher than the levels measured in the Federal-Provincial samples in 1980 (Appendix XXIII). Mean metal levels in Cominco's walleye livers were Cd 9, Pb 3 and Zn 77 µg/g (wet weight). These levels and the 1980 values were higher than the average .2 µg/g Cd and 24 µg/g Zn measured in livers of walleye from the Great Lakes (Lucas et al. 1970).

Table 19

Concentrations of Cd, Cu, Pb and Zn (ug/g wet wt) measured in liver composites from fish collected in May, 1980. Values in parentheses indicate number of fish in composite.

Species and Collection Site	Cd	Cu	Pb	Zn
Birchbank:				
Largescale sucker (5)	2.6	21.	.39	43.
Mountain whitefish (7)	.48	2.2	.10	23.
Northern squawfish (1)	2.1	5.0	.12	22.
Rainbow trout (1)	.08	9.4	.56	28.
Trail:				
Largescale sucker (7)	3.7	16.	2.6	50.
Mountain whitefish (4)	2.4	3.8	3.2	28.
Peamouth (2)	3.6	4.7	.84	21.
Rainbow trout (1)	3.3	54.	4.8	43.
Walleye (1)	1.1	57.	.17	20.
Waneta:				
Largescale sucker (6)	2.8	22.	2.5	53.
Northern squawfish (4)	1.9	7.3	.24	21.
Peamouth (2)	2.0	12.	.38	21.
Walleye (2)	2.1	5.3	.06	21.

Table 20.
Ranges of mean metal concentrations (µg/g) measured in livers of various fish species from different waters.

Location	Cd	Cu	Pb	Zn	Reference
Columbia River[1,3]	.08-3.7	2.2-57	.06-4.8	20-50	This Study
Columbia River[2,3]	.29-12	9.3-217	.25-19	48-186	
Baie du Doré,[1,4] Lake Huron	.16	5.22	.24	15.10	Brown and Chow 1977
Toronto Harbour[1,4]	.13	16.45	1.52	86.04	
Great Lakes[1,4]	.4	9	-	-	Lucas et al. 1970
Fraser River[1,3]	ND-2.61	3.54-399	ND-.36	17.7-49.6	Singleton 1983
5 Lakes near Flin Flon, Manitoba[2]	.4-10.1	34-84	-	-	McFarlane & Franzin 1980
Lake Balaton, Hungary[2]	.65-1.05	7.73-50.7	3.10-3.15	88.1-106	Salanki et al. 1982
"A highly organic softwater pond"[2]	-	4.8-548	-	39.7-338	Weiner and Geisy 1979

[1] Wet weight
[2] Dry weight
[3] Range of values
[4] Mean over all species collected

Usually the highest metal levels were found in fish caught at Trail and the lowest levels in fish caught at Birchbank. For species which were collected at both sites, concentrations of Cd and Pb were much higher (often by a factor of 5 or more) in samples from Trail than in samples from Birchbank. A similar but usually less pronounced trend was observed for Cu and Zn (Table 19).

Concentrations of metals in liver may be more closely related to environmental metal levels than are concentrations in muscle. Wilson et al. (1981) found that concentrations of Cd, Cu and Zn in rainbow trout livers increased with increasing metal concentrations in the water, although metal concentrations in muscles of the same fish were not related to environmental levels. On the other hand, Roch et al. (1982) found no correlation between Zn concentrations in livers of rainbow trout and Zn concentration in water.

V. HEPATIC METALLOTHIONEIN IN RAINBOW TROUT

A. Introduction

Although measurement of heavy metals in fish tissues provides an estimate of the amount of biologically available metal in the environment, it does not give an indication of toxic effects. For example, in laboratory experiments, Biegert and Valkovic (1980) found that whole body accumulation of Hg, Cu, Pb and Zn in rainbow trout and fathead minnows (Pimphales promelas) could not be directly correlated with lethality. McKim et al. (1976) found that brook trout (Salvelinus fontinalis) exposed to methylmercuric chloride accumulated concentrations of Hg in excess of 0.5 μg/g without showing signs of intoxication and without effect on their reproduction. Roch et al. (1982) provide an explanation of these observations, suggesting that measurements of metals in tissue do not distinguish between metal which causes biological response and that which is non-specifically bound and without effect.

For certain metals, the concentration in fish tissue may not even be a reliable indication of bioavailability. Gächter and Geiger (1979) found that trout held in experimental limnocorrals maintained whole body concentrations of Cu and Zn at constant levels regardless of environmental conditions. Roch et al. (1982) found no correlation between Zn concentrations in rainbow trout livers and Zn concentrations in the waters of the Campbell River system to which the fish had been exposed.

For these reasons, Roch et al. (1982) have suggested that some biochemical measure be used to assess the response of fish to the toxic effects of metals. They have assessed the use of hepatic metallothionein, a low molecular weight protein which binds heavy metals, as an indicator of biological response to heavy metal pollution. They have concluded that for both wild-caught and field-caged rainbow trout, the concentration of metallothionein is indicative of the degree of contamination to which the salmonids have been exposed (Roch et al. 1982, Roch and McCarter 1984a). Further, Roch and McCarter (1984b) have discovered a direct relationship between metallothionein levels in rainbow trout livers and LC_{50}s, as determined in laboratory tests using various concentrations of Zn, Cu and Cd in the ratio 400:20:1 (which is characteristic of Buttle Lake in the Campbell River system). From this relationship they have calculated that a concentration of 100 nanomoles metallothionein per gram liver corresponds to .25 toxic units (LC_{10}=1 toxic unit) and represents a "minimal biological effect".

In the following section concentrations of hepatic metallothionein measured in rainbow trout from the Columbia River are reported. These levels are compared with concentrations reported for trout from the Campbell River system (Roch et al. 1982), and the possibility of using metallothionein for monitoring the response of fish to metals in the Columbia River is considered.

B. Methods

Fish used for hepatic metallothionein analyses were the rainbow trout collected downstream from Trail in 1983 (see Section IV-C-3). Livers were removed as described in Section IV-C-4 and immediately placed in a freezer in the mobile laboratory. Frozen samples were packed in a cooler containing dry ice and shipped to the University of Victoria for analysis.

Trout liver samples were analysed for Cd, Cu, Zn and metallothionein using the methods described by Roch et al. (1982).

C. Results and Discussion

Results of metallothionein and metal analyses are presented in Table 21, where they are compared with levels measured in trout from the Campbell River system by Roch et al. (1982). Concentrations of metallothionein and Cu in Columbia River trout were higher than those measured in fish from uncontaminated Upper Quinsam Lake and fell between levels measured in fish from John Hart Lake and fish from Upper Campbell Lake.

The mean metallothionein concentration in Columbia River trout livers, 124 nmol/g, was higher than the 100 nmol/g which Roch and McCarter (1984b) have designated as a "safe" level. If the relationship between metallothionein concentration and toxicity which Roch and McCarter (1984b) observed for metal ratios and hardness characteristic of the Campbell River system is also true for the water quality conditions of the Columbia River, then the Columbia River trout are showing a sublethal response to metal toxicity. However, since there have been no bioassay experiments relating toxicity of Columbia River water to metallothionein concentrations, it is uncertain whether this relationship is the same as for Campbell River waters.

The concentration of metallothionein was significantly correlated with the concentration of Cd in Columbia River trout livers ($r=.75$, $P<.01$). Metallothionein was not significantly correlated with the concentration of either Cu or Zn ($P>.05$). This result differs from the relationship observed in trout from the Campbell River system, in which metallothionein was highly correlated with Cu (Roch et al. 1982, Roch and McCarter 1984a). The significance of this difference is unclear.

Table 21

Metallothionein and metal concentrations in rainbow trout livers. Values are means and standard deviations based on wet weight. Data for the Campbell River System are from Roch et al. (1982), with wet weight conversions for metals provided by Roch (personal communication).

Site	Metallothionein nmol/g	Zinc µg/g	Copper µg/g	Cadmium µg/g
Columbia River (n = 15)	124 ± 35	28 ± 4	63 ± 23	1.5 ± 0.8
Upper Campbell L. (n = 5)	164 ± 37	40 ± 5	125 ± 60	4.0 ± 1.8
John Hart L. (n = 5)	94 ± 18	31 ± 8	49 ± 10	2.2 ± 0.7
Upper Quinsam L. (n = 5)	58 ± 14	31 ± 5	9 ± 4	1.0 ± 0.2

D. Metallothionein as a Monitoring Tool

Metallothionein has potential as a tool for monitoring sublethal response of trout to metal pollution, but its application is not well enough developed to be included in a monitoring program for the Columbia River at this time. Aside from the present study, the only information on the relationship between metallothionein in fish and field metal levels is from the Campbell River system. Data relating metallothionein concentrations to toxicity of metals in a wider range of natural waters, including the Columbia, are required. If it can be shown that metallothionein concentrations above 100 nmoles/g indicate stress and that increasing metallothionein levels are directly related to increased stress for different combinations of metals and other water quality conditions, then metallothionein will provide a useful monitoring tool in the Columbia and in other rivers.

A measure of biological response whose ecological significance is known would be best for monitoring aquatic resources. For example, in an exhaustive field study. McFarlane and Franzin (1978) demonstrated the effects of stress from metals on growth rate, life expectancy, fecundity and reproductive success of white suckers (C. commersoni). Roch and McCarter (1984c) observed a significant reduction in growth of chinook salmon fry (Oncorhynchus tshawytscha) exposed in the laboratory to different concentrations of Cd, Cu and Zn for 21 weeks. Metallothionein concentrations in these fish increased in proportion to the levels of metals to which they had been exposed. If elevated metallothionein levels could be related directly to reduction in growth or to some other measure of stress, it would provide an inexpensive and highly useful method of monitoring ecological response.

VI. CONCLUSIONS

A. Levels in Fish

1. Hg

Mercury levels in all kokanee, largescale suckers, mountain whitefish, peamouth and all but one rainbow trout were well below the 0.5 μg/g Food and Drug Directorate guideline for mercury in fish flesh. In 1981 the mean mercury concentration in walleye approached 0.5 μg/g and may have been increasing; no post-1981 data are available for this species. The mean mercury content in northern squawfish exceeded 0.5 μg/g.

2. Other heavy metals

Since the Canadian Food and Drug Directorate is currently using site- and species-specific assessments, comparisons with guidelines for metals other than mercury cannot be made. However, metals other than lead are lower than guidelines previously used. Concentrations of lead measured in the single sturgeon and in several largescale suckers were more than double the 0.5 μg/g guideline which has been used in the past. Some mountain whitefish and peamouth also had lead concentrations which approached or exceeded this level. The Canadian Food and Drug Directorate should be requested to provide site specific lead guidelines for this reach of the Columbia River.

B. Metal Levels in Columbia River Fish Compared with Fish from Other Areas

Mercury concentrations in Columbia River fish were somewhat higher than levels measured in the same species from most uncontaminated Canadian waters but lower than levels measured in fish from areas of known mercury contamination.

Concentrations of cadmium measured in muscle tissue of Columbia River fish were lower than cadmium levels reported in fish from most other areas, but cadmium concentrations in livers were higher.

Copper concentrations in muscles of Columbia fish were similar to or higher than levels reported in fish from other waters.

Lead concentrations were comparable to levels in fish from some waters receiving known lead discharges but lower than levels in fish from other waters receiving municipal effluents.

Concentrations of zinc in Columbia River fish were generally similar to concentrations in fish from other watersheds.

Chromium concentrations in Columbia River fish were somewhat higher than chromium levels reported in fish from other areas.

C. Metal Concentrations Above and Below Cominco

Concentrations of mercury, cadmium, copper, lead and zinc in fish caught upstream from Cominco were lower than in fish caught downstream in at least one species sampled. This result was expected, since Cominco is the major known source of metals in this stretch of river, but interpretation is made uncertain by lack of knowledge of movement patterns of most fish species.

D. Temporal Trends

Not enough data are available to identify temporal trends for any species. Mercury levels in walleye apparently increased, while cadmium levels in largescale suckers decreased between 1980 and 1981, but neither of these species was collected in 1983. No trends could be established for mountain whitefish which were collected in all three years, partly because differences in analytical techniques used in 1983 made interpretation of temporal differences difficult.

E. Stress on Fish

Elevated metallothionein levels in rainbow trout livers may be interpreted as indicating that the fish are stressed by metals in their environment. The ecological consequences of this stress have not been demonstrated.

VII. RECOMMENDATIONS FOR MONITORING

A. Objectives of a Monitoring Program

A program of monitoring metals in Columbia River fish should have two major objectives:

1) to compare metals levels to Food and Drug Directorate Guidelines for edible fish flesh
2) to monitor temporal trends in biologically available metals.

These two objectives require somewhat different monitoring strategies. Specifically, the species and the organ to be monitored may be different for each objective.

For monitoring with respect to guidelines for edible fish flesh, the fish selected should be

1) species which are frequently consumed, ie. sport fish
2) species which accumulate high levels of toxic metals.

The organ to be monitored should be the organ which is usually eaten: muscle.

For trend monitoring, the fish selected should be

1) species which are abundant enough that adequate numbers can always be collected
2) species which are resident so that metal levels measured in an individual fish will reflect environmental levels where that fish was collected
3) species which accumulate the metal(s) in question in concentrations high enough to be easily measured
4) species in which tissue metal levels show a clear relationship with environmental metal levels.

The organ monitored should accumulate high concentrations of metals which are related to environmental metal levels.

B. Selection of Species to Monitor

1. Hg

a. Levels in fish

Walleye should be monitored. Since this species was the only sport fish in which mercury concentrations approached the 0.5 µg/g Food and Drug Directorate guideline, no other species need be monitored now. If large increases in mercury levels in walleye (eg. mercury concentrations exceeding 1.0 µg/g) are ever observed, then mercury levels in rainbow trout and possibly other less popular sport fish should be measured.

b. Trend monitoring

No species fits all the requirements for trend monitoring for mercury. Suckers and squawfish are probably resident (R.L. & L. Environmental Services 1984, 1985), but there was no apparent relationship between tissue mercury levels and environmental levels for these species. Mountain whitefish are abundant, but the little that is known of their movements suggests an upstream migration of juveniles (R.L. & L. Environmental Services 1982, Ash et al. 1982), which may explain the weak relationship between tissue mercury levels and environmental mercury levels observed for this species. Walleye were the only species in which there appeared to be a relationship between tissue mercury concentrations and environmental mercury levels. However, walleye migrate seasonally (R.L. & L. Environmental Services 1982, Beckman et al. 1985) and cannot always be collected. Thus, although walleye might be useful for regularly scheduled trend monitoring, another species should also be monitored in case unscheduled sampling in response to a spill is necessary. (See Section VII-E.)

2. Other metals

   a. Levels in fish

   Mountain whitefish should be monitored for other heavy metals, as they were the only sport fish except sturgeon in which lead levels were somewhat elevated. Maximum cadmium levels were also higher in whitefish than in other sport fish.

   b. Trend monitoring

   Largescale suckers should be collected for trend monitoring. They are abundant and probably sedentary, and they accumulated higher concentrations of lead and zinc, as well as barium, strontium and manganese, than did most other species. Concentrations of lead and possibly cadmium in sucker muscle appeared to be related to environmental levels.

3. Summary

A monitoring program for metal levels in Columbia River fish should be based on samples of walleye, mountain whitefish, and largescale suckers. This choice of species is consistent with the species selection recommended for the U.S. National Pesticides Monitoring Program (May and McKinney 1981) in that it includes both a predator (walleye) and a bottom-dweller (sucker).

Since only one white sturgeon was collected, it was impossible to draw any conclusions about metal levels in this species, but concentrations of lead and mercury in that individual were high enough to suggest sturgeon may require monitoring. An attempt should be made to obtain more data, perhaps by requesting that local fishermen donate a sample of muscle from any sturgeon that they catch.

C. Selection of Organ to Monitor

Muscle tissue must be used for all monitoring related to comparisons with guidelines for edible fish flesh. Muscle must also be used for trend monitoring if comparisons are to be made with the data presented in this report.

There were not enough data for an evaluation of liver as an organ to monitor in Columbia River fish, but liver could prove better than muscle for trend monitoring. Cadmium, which was often not detectible in muscle tissue, was much more concentrated in liver. In largescale suckers, mountain whitefish and rainbow trout, metal concentrations appeared higher in livers of fish collected from more contaminated areas.

Thus, metal levels in livers should be evaluated further. For this evaluation, replicate samples are needed so that statistical tests can be made. Livers should not be composited, since the results of statistical tests on composite samples are difficult to interpret. Compositing confounds variation among individual fish with variation due to the selection of livers to be included in each composite. Whitefish and suckers should be used for liver samples, if enough tissue can be obtained from them to make compositing unnecessary. If compositing is unavoidable, then replicate composites should be created by pooling equal weights of liver tissue from two or more fish of approximately the same size.

D. Metals to be Monitored

Emphasis should be placed on monitoring for Hg, Cd, Cu, Pb and Zn. Monitoring for Cr should also be considered. All of these metals should be measured in muscles of largescale suckers and mountain whitefish. If analytical costs are a limiting factor, Hg only should be measured in walleye, and Hg should not be measured in livers.

E. Sampling Procedures

At least 15 individuals of each species should be collected. The results of statistical tests performed on 10 or fewer samples were rarely significant. Hakanson (1984) has concluded that 10 samples are too few to provide adequate estimates of metal levels in fish under most circumstances and that the number of samples needed increases with the degree of contamination.

The sizes of fish collected should be representative of the size range of the population. Since in many cases metal concentrations are correlated with the size of fish, a range of fish sizes is needed to represent the range of variability of metal concentrations. A wide range of sizes should also be collected to insure that sizes overlap from year to year; otherwise comparisons of metal levels may be invalid because of errors introduced by extrapolation of metal-size regressions (Moriarty et al. 1984).

Sampling initially should be confined to the area downstream from Cominco. Until more information on the movement patterns of fish is available, comparison of metal levels in fish collected above and below Cominco will have little meaning.

Annual sampling should be carried out for at least 3 years, or until trends can be established. If metal levels are shown to be stable or declining, sampling frequency could be reduced to every other year.

Annual sampling should be timed to insure that walleye can be collected. When a sampling trip is planned, the local Fish and Wildlife Conservation Officer should be consulted to determine whether walleye are present in the river.

If metal concentrations in river increase sharply (eg. a major spill occurs), additional sampling should be undertaken. Such sampling should begin 2-4 weeks after the spill, since field caging experiments have shown that increases in metal concentrations in rainbow trout are measurable after 2-4 weeks (Uthe et al. 1973, Roch and McCarter 1984b). Further sampling may be necessary until metal accumulation by fish reaches a plateau.

F. Laboratory Analytical Procedures

All samples should be analysed by the same laboratory using the same analytical techniques, so that all monitoring data will be comparable.

Quality control analyses should occasionally be performed by two or more laboratories. Samples for quality control analyses should be homogenized prior to being split. Replicate analyses should be performed on the split samples by each laboratory, so that statistical comparisons of their results can be made.

G. Metallothionein

Research on the use of metallothionein as a monitoring tool should be encouraged, but metallothionein analyses should not be included in a monitoring program at the present time.

H. Additional Information

Data on movement patterns of fish, particularly walleye, largescale suckers and mountain whitefish, are necessary if metal levels measured in these species are to be related to sources.

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APPENDICES

APPENDIX I

Sampling information and some biological characteristics of fish collected from the Columbia River in 1980.

Sample Number	Date Collected	Collection Site	Length (mm)
Kokanee:			
6471	Aug. 6, 1980	Waneta	230
Largescale suckers:			
6362	Aug. 5, 1980	Birchbank	470
6363	Aug. 5, 1980	Birchbank	435
6364	Aug. 5, 1980	Birchbank	525
6365	Aug. 5, 1980	Birchbank	440
6366	Aug. 5, 1980	Birchbank	500
6374	Aug. 5, 1980	Old Trail Bridge	500
6375	Aug. 5, 1980	Old Trail Bridge	465
6451	Aug. 5, 1980	Old Trail Bridge	560
6452	Aug. 5, 1980	Old Trail Bridge	440
6453	Aug. 5, 1980	Old Trail Bridge	515
6454	Aug. 5, 1980	Old Trail Bridge	400
6455	Aug. 5, 1980	Old Trail Bridge	465
6465	Aug. 6, 1980	Waneta	435
6466	Aug. 6, 1980	Waneta	425
6467	Aug. 6, 1980	Waneta	390
6468	Aug. 6, 1980	Waneta	455
6469	Aug. 6, 1980	Waneta	445
6470	Aug. 6, 1980	Waneta	400
Mountain whitefish:			
6351	Aug. 5, 1980	Birchbank	335
6352	Aug. 5, 1980	Birchbank	310
6353	Aug. 5, 1980	Birchbank	205
6355	Aug. 5, 1980	Birchbank	330
6356	Aug. 5, 1980	Birchbank	415
6357	Aug. 5, 1980	Birchbank	230
6358	Aug. 5, 1980	Birchbank	375
6359	Aug. 5, 1980	Birchbank	335
6369	Aug. 5, 1980	Old Trail Bridge	370
6370	Aug. 5, 1980	Old Trail Bridge	365
6371	Aug. 5, 1980	Old Trail Bridge	355
6456	Aug. 5, 1980	Old Trail Bridge	265

Appendix I (Cont'd)

Sample Number	Date Collected	Collection Site	Length (mm)
Northern squawfish:			
6361	Aug. 5, 1980	Birchbank	470
6459	Aug. 6, 1980	Waneta	280
6460	Aug. 6, 1980	Waneta	315
6463	Aug. 6, 1980	Waneta	325
6464	Aug. 6, 1980	Waneta	400
Peamouth:			
6372	Aug. 5, 1980	Old Trail Bridge	320
6373	Aug. 5, 1980	Old Trail Bridge	295
6461	Aug. 6, 1980	Waneta	300
6462	Aug. 6, 1980	Waneta	295
Rainbow trout:			
6360	Aug. 5, 1980	Birchbank	200
6367	Aug. 5, 1980	Old Trail Bridge	590
Walleye:			
6368	Aug. 5, 1980	Old Trail Bridge	365
6457	Aug. 6, 1980	Waneta	315
6458	Aug. 6, 1980	Waneta	330

APPENDIX II

Concentrations of Hg (ug/g wet weight) measured in fish collected from the Columbia River, August 5-6, 1980.

Species and Sample Number	Provincial Laboratory	Federal Laboratory (Replicates)	
Kokanee:			
6471	.11		
Largescale suckers:			
6362	.21	.18	.19
6363	.12		
6364	.16	.14	.13
6365	.16		
6366	.15		
6374	.16	.17	.19
6375	.11		
6451	.16	.13	.15
6452	.22		
6453	.20		
6454	.15		
6455	.13	.12	.13
6465	.19	.18	.18
6466	.15		
6467	.09		
6468	.21	.19	.19
6469	.19	.16	.19
6470	.11		
Mountain whitefish:			
6351	.10		
6352	.09		
6353	.06		
6355	.21		
6356	.13	.12	.12
6357	<.05		
6358	.14	.12	.13
6359	.10		
6369	.15		
6370	.15		
6371	.16		
6456	.09		

Appendix II (Cont'd)

Species and Sample Number	Provincial Laboratory	Federal Laboratory (Replicates)	
Northern squawfish:			
6361	.79		
6459	.26		
6460	.24		
6463	.70		
6464	.86	.83	.75
Peamouth:			
6372	.27		
6373	.21		
6461	.20		
6462	.26		
Rainbow trout:			
6360	<.05		
6367	.17	.13	.17
Walleye:			
6368	.23		
6457	.25		
6458	.16		

APPENDIX IIIa

Concentrations (ug/g wet weight) of Cd, Cu, Pb and Zn measured in muscle of fish collected from the Columbia River, August 5-6, 1980.

Species and Sample Number	Cd	Cu	Pb	Zn
Kokaneee:				
6471	.019	.73	<.011	8.3
Largescale suckers:				
6362	<.011	.52	.16	7.3
6363	.021	.98	.17	6.3
6364	.058	1.1	.12	7.5
6365	<.010	1.1	.18	6.2
6366	.015	4.5	.22	5.3
6374	.019	1.6	1.6	6.5
6375	.014	.52	.44	9.7
6451	.022	.82	1.2	7.4
6452	.038	.81	1.5	15.
6453	.055	.61	.35	7.7
6454	.044	.66	.042	5.6
6455	.11	.72	.41	5.8
6465	.016	.63	.48	11.
6466	.013	.88	.33	8.9
6467	.015	.76	.29	8.2
6468	.070	.57	.25	11.
6469	.013	1.4	.84	9.9
6470	.012	1.5	.27	8.9
Mountain whitefish:				
6351	<.014	.65	.014	4.0
6352	<.013	1.1	.18	4.1
6353				
6355	<.014	1.6	.027	4.0
6356	<.013	1.1	.091	4.4
6357	.023	.88	.048	5.3
6358	<.011	.62	.15	4.1
6359	<.014	.98	<.014	4.2
6369	.026	.72	.069	5.4
6370	.040	.93	.094	5.3
6371	.035	.76	.32	6.2
6456	.051	.96	.36	6.5

Appendix IIIa (Cont'd)

Species and Sample Number	Cd	Cu	Pb	Zn
Northern squawfish:				
6361	.014	.76	.11	3.7
6459	.018	.75	.028	4.9
6460	.012	.62	.030	5.1
6463	.012	3.3	<.011	7.2
6464	.020	.87	.032	5.9
Peamouth:				
6372	.055	1.0	.74	10.
6373	.026	1.2	.15	7.9
6461	.011	.53	.11	7.4
6462	.030	4.0	.071	8.0
Rainbow trout:				
6367	.065	1.4	.27	5.4
Walleye:				
6368	.030	.72	.065	4.6
6457	<.010	.79	<.010	4.8
6458	.015	.56	<.010	4.5

APPENDIX IIIb

Concentrations (ug/g wet weight) of other metals measured in muscle of fish collected from the Columbia River, August 5-6, 1980.

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Kokaneee:						
6471	<.97	<.032	<.16	4.8	.085	.11
Largescale suckers:						
6362	<.96	<.032	<.16	2.7	.26	.42
6363	<.98	<.033	.50	2.0	.34	.33
6364	<1.1	<.035	.77	5.6	.32	.44
6365	<.88	.030	1.6	4.5	.30	.49
6366	<.84	<.028	.31	2.0	.29	.26
6374	<1.0	<.034	<.17	3.0	.39	.63
6375	<.92	<.031	.16	3.4	.37	.33
6451	<1.0	<.034	.21	3.6	.40	.46
6452	<.89	.056	.32	3.7	1.2	.81
6453	.99	<.033	.18	2.3	.20	.27
6454	<.82	<.027	.57	4.4	.35	.50
6455	<.91	.052	.26	1.8	.47	.83
6465	<.90	<.030	.17	3.0	.45	.34
6466	<.88	<.029	.28	3.5	.53	.36
6467	<.89	<.030	.24	4.1	.41	.39
6468	<.93	<.031	.17	3.8	.50	.61
6469	<.91	<.030	.37	4.8	.67	.43
6470	<1.1	<.036	<.18	4.1	.48	.37
Mountain whitefish:						
6351	<1.2	<.041	2.7	3.8	.15	.12
6352	<1.2	<.040	9.5	3.1	.18	.31
6353						
6355	<1.2	<.041	3.2	2.9	.17	.33
6356	<1.2	<.039	1.6	7.0	.16	.31
6357	<1.2	<.038	.37	4.2	.21	.31
6358	<1.0	<.034	<.17	11.	.13	.16
6359	<1.3	<.044	3.4	5.4	.15	.13
6369	<1.4	<.045	<.23	8.2	.13	.15
6370	<1.3	<.042	.31	10.	.14	.15
6371	1.7	<.044	.50	7.7	.13	.076
6456	<1.3	<.043	.46	5.2	.14	.10

Appendix IIIb (Cont'd)

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Northern squawfish:						
6361	<.81	.083	.44	5.0	.19	.90
6459	<.95	<.032	.49	3.6	.21	.48
6460	<.98	<.033	.28	3.2	.19	.35
6463	<1.0	<.033	.58	4.7	.19	.51
6464	<.93	.094	.35	4.6	.17	.58
Peamouth:						
6372	<1.1	.31	.32	6.3	.24	1.0
6373	<1.1	.038	.29	5.3	.20	.50
6461	<.86	.13	<.14	4.9	.17	.46
6462	<1.0	.040	<.17	4.7	.18	.40
Rainbow trout:						
6367	<1.2	<.041	.24	5.9	.11	.39
Walleye:						
6368	<.94	<.031	.72	1.8	.12	.16
6457	<.90	<.030	.25	4.4	.14	.045
6458	<.92	<.031	.34	1.7	.13	.14

APPENDIX IVa

Concentrations (ug/g dry weight) of Cd, Cu, Pb and Zn measured in muscle of fish collected from the Columbia River, August 5-6, 1980.

Species and Sample Number	Cd	Cu	Pb	Zn
Kokaneee:				
6471	.085	3.2	<.047	36.
Largescale suckers:				
6362	<.048	2.4	.72	33.
6363	.089	4.2	.73	27.
6364	.24	4.4	.49	31.
6365	<.047	5.3	.88	30.
6366	.077	23.	1.1	27.
6374	.085	6.9	6.8	29.
6375	.065	2.5	2.1	46.
6451	.098	3.6	5.1	33.
6452	.18	3.9	7.2	74.
6453	.25	2.7	1.6	35.
6454	.24	3.5	.23	30.
6455	.52	3.4	1.9	28.
6465	.078	3.1	2.4	53.
6466	.060	4.2	1.6	42.
6467	.070	3.6	1.4	39.
6468	.093	2.7	1.2	51.
6469	.063	6.5	4.0	47.
6470	.049	6.1	1.1	37.
Mountain whitefish:				
6351	<.047	2.2	.048	14.
6352	<.047	3.8	.63	15.
6353				
6355	<.050	5.9	.10	15.
6356	<.047	4.1	.33	16.
6357	.088	3.4	.19	20.
6358	<.046	2.6	.61	17.
6359	<.048	3.3	<.048	14.
6369	.082	2.3	.22	17.
6370	.14	3.1	.32	18.
6371	.11	2.4	1.0	20.
6456	.18	3.3	1.2	23.

Appendix IVa (Cont'd)

Species and Sample Number	Cd	Cu	Pb	Zn
Northern squawfish:				
6361	.070	3.9	.55	19.
6459	.081	3.4	.13	22.
6460	.053	2.7	.13	23.
6463	.054	14.	<.049	32.
6464	.089	4.0	.15	27.
Peamouth:				
6372	.22	4.1	3.0	41.
6373	.11	5.1	.64	33.
6461	.058	2.7	.54	37.
6462	.13	17.	.30	33.
Rainbow trout:				
6367	.24	5.0	.98	20.
Walleye:				
6368	.14	3.4	.30	22.
6457	<.047	3.7	<.047	23.
6458	.072	2.6	<.048	21.

APPENDIX IVb

Concentrations (ug/g dry weight) of other metals measured in muscle of fish collected from the Columbia River, August 5-6, 1980.

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Kokaneee:						
6471	<4.2	<.14	<.71	21.	.37	.48
Largescale suckers:						
6362	<4.3	<.15	<.72	12.	1.2	1.9
6363	<4.2	<.14	2.2	8.5	1.5	1.4
6364	<4.4	<.15	3.2	23.	1.4	1.8
6365	<4.3	.15	8.0	22.	1.5	2.4
6366	<4.3	<.14	1.6	11.	1.5	1.3
6374	<4.5	<.15	<.75	13.	1.7	2.7
6375	<4.3	<.15	.77	16	1.7	1.6
6451	<4.4	<.15	.93	16.	1.7	2.0
6452	<4.3	.27	1.5	18.	5.6	3.9
6453	4.5	<.15	.79	11.	.90	1.2
6454	<4.4	<.15	3.0	24.	1.9	2.7
6455	<4.3	.25	1.2	8.5	2.2	3.9
6465	<4.4	<.15	.83	15.	2.2	1.6
6466	<4.2	<.14	1.4	17.	2.5	1.7
6467	<4.2	<.14	1.1	19.	2.0	1.8
6468	<4.4	<.15	.79	18.	2.4	2.9
6469	<4.3	<.14	1.7	23.	3.2	2.0
6470	<4.4	<.15	<.74	17.	2.0	1.5
Mountain whitefish:						
6351	<4.3	<.14	9.2	13.	.53	.41
6352	<4.3	<.14	34.	11.	.63	1.1
6353						
6355	<4.5	<.15	12.	11.	.62	1.2
6356	<4.3	<.14	6.0	26.	.60	1.1
6357	<4.4	<.15	1.4	16.	.80	1.2
6358	<4.2	<.14	<.70	46.	.52	.64
6359	<4.4	<.15	11.	18.	.50	.44
6369	<4.4	<.15	<.73	26.	.42	.49
6370	<4.2	<.14	1.0	34.	.47	.52
6371	5.2	<.14	1.6	24.	.40	.24
6456	<4.5	<.15	1.6	18.	.48	.36

Appendix IVb (Cont'd)

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Northern squawfish:						
6361	<4.2	.43	2.3	25.	.97	4.6
6459	<4.3	<.14	2.2	16.	.96	2.2
6460	<4.3	<.14	1.3	14.	.84	1.5
6463	<4.4	<.15	2.5	21.	.84	2.2
6464	<4.2	.43	1.6	21.	.79	2.6
Peamouth:						
6372	<4.4	1.3	1.3	26.	1.0	4.1
6373	<4.5	.16	1.2	22.	.84	2.0
6461	<4.4	.65	<.73	25.	.87	2.4
6462	<4.3	.17	<.72	20.	.77	1.7
Rainbow trout:						
6367	<4.4	<.15	.88	21.	.39	1.4
Walleye:						
6368	<4.4	<.15	3.4	8.5	.56	.73
6457	<4.3	<.14	1.2	21.	.64	.21
6458	<4.3	<.14	1.6	8.1	.62	.67

APPENDIX V

Concentrations of other metals (ug/g wet wt) measured in liver composites from fish collected in May, 1980. Values in parentheses indicate number of fish in composite.

Species and Collection Site	Al	Ba	Cr	Fe	Mn	Sr	Ti
Birchbank:							
Largescale sucker (5)	3.7	<.035	.20	293	1.3	.09	.11
Mountain whitefish (7)	<1.1	<.035	.18	113	1.2	.065	.11
Northern squawfish (1)	4.9	.15	.73	369	.69	.096	.13
Rainbow trout (1)	<1.3	<.042	.26	69.	1.9	.11	.13
Trail:							
Largescale sucker (7)	2.2	<.044	.25	194	1.0	<.059	<.13
Mountain whitefish (4)	1.5	<.033	.24	250	1.3	.12	.13
Peamouth (2)	<1.9	<.062	<.31	58.	.67	.10	<.18
Rainbow trout (1)	3.2	<.035	.21	433	1.1	.14	<.099
Walleye (1)	<1.3	<.042	.44	67.	.99	.09	<.12
Waneta:							
Largescale sucker (6)	2.5	<.042	<.21	279	2.0	.11	<.12
Northern squawfish (4)	<1.3	<.042	.38	121	1.2	.13	.13
Peamouth (2)	2.3	<.063	<.32	54.	1.1	<.084	<.18
Walleye (2)	<1.1	<.036	<.18	174	.99	.096	<.10

APPENDIX VIa

Concentrations of Cd, Cu, Pb and Zn (ug/g dry wt) measured in liver composites from fish collected in May, 1980. Values in parentheses indicate number of fish in composite.

Species and Collection Site	Cd	Cu	Pb	Zn
Birchbank:				
Largescale sucker (5)	11.	87.	1.6	177
Mountain whitefish (7)	2.0	9.3	.40	94.
Northern squawfish (1)	8.7	21.	.48	94.
Rainbow trout (1)	.29	33.	2.0	99.
Trail:				
Largescale sucker (7)	12.	52.	8.5	163
Mountain whitefish (4)	11.	17.	14.	124
Peamouth (2)	8.3	11.	1.9	49.
Rainbow trout (1)	13.	217	19.	175
Walleye (1)	3.8	190	.58	66.
Waneta:				
Largescale sucker (6)	9.7	79.	8.6	186
Northern squawfish (4)	6.5	25.	.81	74.
Peamouth (2)	4.7	28.	.88	48.
Walleye (2)	8.6	22.	.25	89.

APPENDIX VIb

Concentrations of other metals (ug/g dry wt) measured in liver composites from fish collected in May, 1980. Values in parentheses indicate number of fish in composite.

Species and Collection Site	Al	Ba	Cr	Fe	Mn	Sr	Ti
Birchbank:							
Largescale sucker (5)	16.	<.15	.83	1220	5.2	.39	.44
Mountain whitefish (7)	<4.4	<.15	.74	470	5.0	.27	.44
Northern squawfish (1)	21.	.64	3.0	1550	2.9	.40	.53
Rainbow trout (1)	<4.4	<.15	.93	245	6.6	.40	.46
Trail:							
Largescale sucker (7)	7.1	<.15	.83	636	3.3	<.19	<.41
Mountain whitefish (4)	6.8	<.15	1.1	1110	5.9	.54	.59
Peamouth (2)	<4.3	<.14	<.71	132	1.5	.24	<.40
Rainbow trout (1)	13.	<.14	.84	1750	4.3	.55	<.40
Walleye (1)	<4.2	<.14	1.4	222	3.3	.31	<.40
Waneta:							
Largescale sucker (6)	8.6	<.15	<.74	979	7.2	.37	<.42
Northern squawfish (4)	<4.4	<.15	1.3	420	4.1	.46	.46
Peamouth (2)	5.3	<.15	<.73	126	2.7	<.20	<.42
Walleye (2)	<4.5	<.15	<.74	729	4.1	.40	<.42

APPENDIX VII

Cominco's 1980 Columbia River fish monitoring data. Hg concentrations are expressed as ug/g wet weight.

Species	Date Collected	Site	Weight (g)	Hg Liver	Hg Muscle
Cutthroat trout	August 14, 1980	Below Cominco	1362	.45	.08
Rainbow trout	April 29, 1980	Above Cominco	1362	.17	-
	August 6, 1980	Above Cominco	567	.09	.06
	August 6, 1980	Above Cominco	454	.10	.03
	August 6, 1980	Above Cominco	2951	.09	.03
	August 15, 1980	Above Cominco	1362	.18	.16
	August 16, 1980	Above Cominco	1362	.10	.03
	August 16, 1980	Above Cominco	2270	.09	.06
	September 9, 1980	Above Cominco	2724	.06	.05
	September 9, 1980	Above Cominco	1930	.31	.08
	September 9, 1980	Above Cominco	1135	.04	.03
	September 15, 1980	Above Cominco	1135	1.4	.55
	September 15, 1980	Above Cominco	2043	.03	.03
	September 16, 1980	Above Cominco	2270	.06	.03
	September 16, 1980	Above Cominco	1589	.04	.03
	October 6, 1980	Above Cominco	1816	.09	.03
	October 16, 1980	Above Cominco	1589	.03	.02
	October 16, 1980	Above Cominco	681	.02	.02
	October 16, 1980	Above Cominco	1816	.03	.03
	October 16, 1980	Above Cominco	1135	.05	.06
	April 29, 1980	Below Cominco	1362	.18	-
	June 29, 1980	Below Cominco	454	.09	-
	June 29, 1980	Below Cominco	1362	.16	.14
	July 2, 1980	Below Cominco	1589	.43	.07
	July 8, 1980	Below Cominco	1362	.84	.11
	August 20, 1980	Below Cominco	1362	.36	.05
	September 9, 1980	Below Cominco	908	.19	.03
	September 9, 1980	Below Cominco	908	.26	.04
	September 9, 1980	Below Cominco	1135	.43	.07
	October 3, 1980	Below Cominco	631	.04	.02
	October 3, 1980	Below Cominco	681	.05	.04
	October 3, 1980	Below Cominco	681	.04	.01
	October 17, 1980	Below Cominco	1816	.90	.07
	October 17, 1980	Below Cominco	2043	.30	.07
Walleye	October 3, 1980	Below Cominco	567	1.1	.36
	October 3, 1980	Below Cominco	681	.44	.20
	October 3, 1980	Below Cominco	454	1.0	.21
	October 17, 1980	Below Cominco	681	.42	.40
	October 17, 1980	Below Cominco	681	.30	.48
	October 17, 1980	Below Cominco	908	1.1	.35
	October 17, 1980	Below Cominco	681	.14	.18

APPENDIX VIII

Sampling information and some biological characteristics of fish collected from the Columbia River in 1981. SC = scales, SO = scales and otoliths, R = not readable

Sample Number	Date Collected	Collection Site	Weight (g)	Length (mm)	Sex	Age	Aging Method	Maturity
Largescale suckers:								
7197	Nov. 2, 1981	Old Trail Bridge	1530	520		5	SO	
7198	Nov. 2, 1981	Old Trail Bridge	1020	431		5	SO	
7199	Nov. 2, 1981	Old Trail Bridge	1250	488		5	SO	
7203	Nov. 2, 1981	Old Trail Bridge	980	456	F	6+	SO	
7204	Nov. 2, 1981	Old Trail Bridge	1250	485		R	SO	
7205	Nov. 2, 1981	Old Trail Bridge	1820	551		R	SO	
7211	Nov. 3, 1981	Waneta	950	425		5	SO	
7212	Nov. 3, 1981	Waneta	880	424		6+	SO	
7213	Nov. 3, 1981	Waneta	1040	435		5	SO	
7214	Nov. 3, 1981	Waneta	1165	478		R	SO	
7215	Nov. 3, 1981	Waneta	1185	460		5	SO	
Mountain whitefish:								
7192	Nov. 2, 1981	Old Trail Bridge	650	375		6	SC	
7193	Nov. 2, 1981	Old Trail Bridge	730	376	F	4	SC	Mature
7194	Nov. 2, 1981	Old Trail Bridge	770	391	F	5	SC	Mature
7195	Nov. 2, 1981	Old Trail Bridge	600	367	F	5	SO	Mature
7196	Nov. 2, 1981	Old Trail Bridge	300	341		4	SC	
7208	Nov. 3, 1981	Old Trail Bridge	50	188		1+	SC	Juvenile
7210	Nov. 3, 1981	Old Trail Bridge	55	190		1+	SC	Juvenile
7216	Nov. 3, 1981	Waneta	430	367		5	SO	
7217	Nov. 3, 1981	Waneta	490	400		5	SO	
7218	Nov. 3, 1981	Waneta	105	210		2	SC	Juvenile
7221	Nov. 3, 1981	Waneta	1010	410		3+	SO	
7222	Nov. 3, 1981	Waneta	520	345		R	SC	
7223	Nov. 3, 1981	Waneta	350	355		4+	SO	
Northern squawfish:								
7206	Nov. 2, 1981	Old Trail Bridge	1600	500	M	R	SO	
7207	Nov. 3, 1981	Old Trail Bridge	850	420		R	SO	
7219	Nov. 3, 1981	Waneta	640	410		7	SO	
7220	Nov. 3, 1981	Waneta	800	378		8	SO	

Appendix VIII (Cont'd)

Sample Number	Date Collected	Collection Site	Weight (g)	Length (mm)	Sex	Age	Aging Method	Maturity
Rainbow trout:								
7191	Nov. 2, 1981	Old Trail Bridge	840	440	F	R	SO	Spawned this year
Walleye:								
7189	Nov. 2, 1981	Old Trail Bridge	670	410		5	SO	
7190	Nov. 2, 1981	Old Trail Bridge	1910	543		5	SO	
7224	Nov. 3, 1981	Waneta	910	435		4	SO	
7225	Nov. 3, 1981	Waneta	790	418		3+	SO	

APPENDIX IX

Concentrations of Hg (ug/g wet weight) measured in fish collected from the Columbia River, November 2-3, 1981.

Species and Sample Number	Provincial Laboratory	Federal (EPS) Laboratory
Largescale suckers:		
7197	.16	.15
7198	.15	.12
7199	.12	.10
7203	.17	.17
7204	.12	.13
7205	.22	.21
7211	.12	.12
7212	.20	.18
7213	.10	.11
7214	.13	.11
7215	.12	.09
Mountain whitefish:		
7192	.22	.19
7193	.14	.14
7194	.17	.18
7195	.19	.19
7196	.15	.12
7208, 7210*	.05	.06
7216	.27	.18
7217	.20	.17
7218	<.05	.04
7221	.09	.09
7222	.12	.13
7223	.19	.17
Northern squawfish:		
7206	.64	.56
7207	.47	.42
7219	.91	.73
7220	.45	.35

* composite sample

Appendix IX (Cont'd)

Species and Sample Number	Provincial Laboratory	Federal (EPS) Laboratory
Rainbow trout:		
7191	.12	.11
Walleye:		
7189	.49	.44
7190	.31	.25
7224	.45	.33
7225	.36	.28

APPENDIX X

Mercury in livers of fish collected from the Columbia River in November, 1981. Most samples are composites from two or more fish. Values are expressed as ug/g wet weight.

Species	Sample Numbers	Hg
Largescale sucker	7197,7203,7204	.21
	7198,7199,7205	.19
	7211,7212,7213,7214,7215	.26
Mountain whitefish	7192,7193,7196	.39
	7194,7195	.45
	7208,7210	.06
	7221	.28
	7222,7223	.43
Northern squawfish	7206	.47
	7207	1.3
	7219,7220	.27
Rainbow trout	7191	.18
Walleye	7189	.17
	7190	.17
	7224,7225	.29

APPENDIX XIa

Concentrations (ug/g wet weight) of Cd, Cu, Pb and Zn measured in muscle of fish collected from the Columbia River, November 2-3, 1981.

Species and Sample Number	Cd	Cu	Pb	Zn
Largescale suckers:				
7197	.01	.68	.82	5.2
7198	<.01	.83	.42	9.3
7199	.01	1.0	.57	7.5
7203	<.01	.61	.38	8.8
7204	<.01	.62	.26	6.6
7205	<.01	1.3	1.2	15.
7211	<.01	1.1	.17	8.7
7212	.02	1.0	.19	11.
7213	<.01	1.6	.17	11.
7214	.01	1.1	.07	7.5
7215	.02	.80	.087	9.8
Mountain whitefish:				
7192	.025	.79	.19	3.8
7193	.01	.74	.052	5.3
7194	.053	1.1	.53	5.0
7195	.01	.76	.21	4.1
7196	.017	1.2	.026	4.9
*7208, 7210	<.01	1.2	.021	5.7
7216	.008	.75	.30	6.2
7217	.024	1.4	.073	5.2
7218	<.01	2.3	.043	6.1
7221	<.01	1.2	.068	4.4
7222	.025	1.1	.099	3.8
7223	.019	1.0	.091	4.0
Northern squawfish:				
7206	.021	.63	.09	5.0
7207	.044	.99	.20	6.5
7219	<.01	1.7	.11	6.9
7220	<.01	1.2	.074	4.8

* composite sample

Appendix XIa (Cont'd)

Species and Sample Number	Cd	Cu	Pb	Zn
Rainbow trout:				
7191	.02	.89	.058	5.6
Walleye:				
7189	<.01	.52	.01	5.0
7190	.01	.79	.022	5.0
7224	<.01	.69	.01	5.7
7225	<.01	.86	.022	6.1

APPENDIX XIb

Concentrations (ug/g wet weight) of other metals measured in muscle of fish collected from the Columbia River, November 2-3, 1981.

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Largescale suckers:						
7197	<.94	.062	.26	5.1	.20	.33
7198	<1.0	.062	.21	5.1	.36	.41
7199	<1.0	.068	.18	4.9	.25	.47
7203	<.92	.096	.25	4.0	.30	.51
7204	<1.1	.075	.29	5.7	.31	.57
7205	<1.1	.10	.20	4.9	.29	.47
7211	<1.0	.038	<.16	6.3	.29	.26
7212	<.93	.11	.17	6.6	.59	.58
7213	<1.0	.058	.31	4.7	.42	.34
7214	<.98	.069	.59	7.5	.40	.35
7215	<.96	.079	.18	8.9	.35	.35
Mountain whitefish:						
7192	<1.2	<.037	.19	14.	.068	.23
7193	<1.3	<.039	.20	10.	.045	.11
7194	<1.4	<.041	.26	10.	.080	.27
7195	<1.2	.040	.33	14.	.16	.44
7196	<.85	.045	.30	18.	.14	.39
*7208, 7210	<1.0	<.031	.23	4.4	.081	.17
7216	.86	.026	.12	33.	.099	.28
7217	<.81	<.024	.22	21.	.057	.12
7218	<1.1	<.033	<.16	4.8	.12	.10
7221	<1.4	<.041	<.20	4.9	.086	.20
7222	<1.2	<.037	.31	13.	.080	.21
7223	<.92	<.028	.22	18.	.11	.29
Northern squawfish:						
7206	<1.0	.19	.17	3.6	.14	.55
7207	<1.1	.20	.29	11.	.11	.32
7219	<.95	.63	.19	8.5	.17	.25
7220	<1.1	.12	.21	7.3	.093	.22

* composite sample

Appendix XIb (Cont'd)

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Rainbow trout:						
7191	<.95	<.028	.16	5.0	<.019	.08
Walleye:						
7189	<.98	<.029	.20	3.4	.036	.15
7190	<1.0	<.031	.28	5.4	.023	<.04
7224	<1.0	<.031	.21	4.7	<.020	.10
7225	<1.1	.064	<.16	7.7	.11	.08

APPENDIX XIIa

Concentrations (ug/g dry weight) of Cd, Cu, Pb and Zn measured in muscle of fish collected from the Columbia River, November 2-3, 1981.

Species and Sample Number	Cd	Cu	Pb	Zn
Largescale suckers:				
7197	.05	3.4	4.1	26.
7198	<.05	3.8	1.9	43.
7199	.05	4.8	2.7	36.
7203	<.05	3.2	2.0	46.
7204	<.05	2.8	1.2	30.
7205	<.05	5.3	5.2	65.
7211	<.05	5.1	.80	42.
7212	.09	5.3	.95	54.
7213	<.05	7.7	.82	52.
7214	.05	5.2	.34	37.
7215	.09	3.9	.42	48.
Mountain whitefish:				
7192	.10	3.2	.78	15.
7193	.05	2.8	.20	20.
7194	.18	3.7	1.8	17.
7195	.05	3.2	.86	17.
7196	.10	7.2	.15	28.
*7208, 7210	<.05	5.9	.10	27.
7216	.05	4.7	1.9	39.
7217	.14	8.0	.42	30.
7218	<.05	10.	.19	27.
7221	<.05	4.5	.25	16.
7222	.10	4.4	.39	15.
7223	.10	5.4	.49	22.
Northern squawfish:				
7206	.10	3.0	.43	24.
7207	.19	4.2	.85	28.
7219	<.05	8.6	.59	36.
7220	<.05	5.3	.32	21.

* composite sample

Appendix XIIa (Cont'd)

Species and Sample Number	Cd	Cu	Pb	Zn
Rainbow trout:				
7191	.09	4.3	.28	27.
Walleye:				
7189	<.05	2.6	.05	25.
7190	.05	3.6	.10	23.
7224	<.05	3.2	.05	26.
7225	<.05	3.9	.10	28.

APPENDIX XIIb

Concentrations (ug/g dry weight) of other metals measured in muscle of fish collected from the Columbia River, November 2-3, 1981.

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Largescale suckers:						
7197	<4.7	.31	1.3	25.	1.0	1.7
7198	<4.8	.28	.95	23.	1.6	1.9
7199	<4.8	.32	.84	23.	1.2	2.2
7203	<4.8	.50	1.3	21.	1.6	2.7
7204	<4.9	.34	1.3	26.	1.4	2.6
7205	<4.7	.43	.82	21.	1.2	2.0
7211	<5.0	.18	<.75	30.	1.4	1.3
7212	<4.7	.55	.84	34.	3.0	3.0
7213	<4.8	.28	1.5	23.	2.0	1.6
7214	<4.8	.34	2.9	37.	2.0	1.7
7215	<4.7	.38	.87	43.	1.7	1.7
Mountain whitefish:						
7192	<4.9	<.15	.78	58.	.28	.91
7193	<5.0	<.15	.75	39.	.17	.41
7194	<4.6	<.14	.87	35.	.27	.90
7195	<4.8	.17	1.4	58.	.65	1.8
7196	<4.9	.26	1.7	103	.79	2.3
*7208, 7210	<4.9	<.15	1.1	21.	.39	.79
7216	5.4	.16	.74	209	.62	1.8
7217	<4.7	<.14	1.3	123	.33	.70
7218	<4.8	<.15	<.72	21.	.54	.46
7221	<5.0	<.15	<.74	18.	.31	.72
7222	<4.9	<.15	1.2	51.	.32	.85
7223	<4.9	<.15	1.2	94.	.57	1.6
Northern squawfish:						
7206	<4.8	.93	.79	17.	.66	2.6
7207	<4.7	.85	1.2	46.	.47	1.4
7219	<4.9	3.3	.97	44.	.86	1.3
7220	<4.6	.54	.93	32.	.40	.96

* composite sample

Appendix XIIb (Cont'd)

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Rainbow trout:						
7191	<4.6	<.14	.76	24.	<.09	.39
Walleye:						
7189	<4.8	<.14	.96	17.	.18	.72
7190	<4.8	<.14	1.3	25.	.11	<.19
7224	<4.7	<.14	.98	22.	<.093	.46
7225	<4.9	.29	<.74	35.	.48	.37

APPENDIX XIII

Sampling information and some biological characteristics of fish collected from the Columbia River in 1981 by R. L. & L. Environmental Services. Abbreviations as in Appendix VIII.

Sample Number	Date Collected	Collection Site	Weight (g)	Length (mm)	Sex	Age	Aging Method	Maturity
Bridgelip sucker:								
2049	Sept. 6, 1981	Columbia Km 51.5	800	395	F	6	SC	Mature
Kokanee:								
1838	Aug. 25, 1981	Columbia Km 47.5	1520	470	M	3	SC	Ripe
1843	Aug. 25, 1981	Norns Creek	1480	508	M	4	SO	Ripe
1863	Aug. 26, 1981	Norns Creek	1400	494	F	3	SO	Spent
1864	Aug. 26, 1981	Norns Creek	1450	474	M	3	SO	Ripe
1865	Aug. 26, 1981	Norns Creek	1900	509	M	3	SO	Ripe
1866	Aug. 26, 1981	Norns Creek	1300	488	F	4	SO	Spent
1955	Aug. 29, 1981	Deer Creek	110	217	M	2	SO	Gravid
1956	Sept. 2, 1981	Deer Creek	110	221	M	2	SO	Gravid
1957	Sept. 2, 1981	Deer Creek	130	234	M	3	SO	Ripe
1958	Sept. 2, 1981	Deer Creek	100	217	M	2	SO	Gravid
1959	Sept. 2, 1981	Deer Creek	170	244	M	3	SO	Ripe
1960	Sept. 2, 1981	Deer Creek	120	220	F	3	SO	Ripe
1961	Sept. 2, 1981	Deer Creek	140	239	F	3	SO	Gravid
1962	Sept. 2, 1981	Deer Creek	110	218	M	4	SO	Gravid
1963	Sept. 2, 1981	Deer Creek	220	260	M	3	SO	Ripe
1964	Sept. 2, 1981	Deer Creek	150	239	M	3	SO	Ripe
Largescale suckers:								
1832	Aug. 25, 1981	Columbia Km 47.5	1080	431	F	7	SC	Mature
1835	Aug. 25, 1981	Columbia Km 47.5	1160	439	F	7	SC	Mature
1836	Aug. 25, 1981	Columbia Km 47.5	950	416	M	6	SC	Mature
1837	Aug. 25, 1981	Columbia Km 47.5	1460	449	F	7	SC	Mature
Mountain whitefish:								
1846	Aug. 26, 1981	Columbia Km 54.2	680	340	F	5	SO	Mature
1847	Aug. 26, 1981	Columbia Km 54.2	621	328	F	5	SO	Gravid
1848	Aug. 26, 1981	Columbia Km 54.2	600	337	M	5	SO	Mature
1855	Aug. 26, 1981	Columbia Km 54.2	650	342	F	5	SO	Mature
1951	Sept. 2, 1981	Columbia Km 8.0	720	363	F	6	SO	Mature
1952	Sept. 2, 1981	Columbia Km 8.6*	550	360	M	6	SO	Mature
1983	Sept. 3, 1981	Columbia Km 8.0*	470	325	F	5	SO	Gravid
1984	Sept. 3, 1981	Columbia Km 8.0*	660	382	F	6	SO	Mature
1991	Sept. 4, 1981	Columbia Km 8.0*	690	364	M	6	SO	Mature
2008	Sept. 5, 1981	Columbia Km 51.5	760	365		6	SC	

Appendix XIII (Cont'd)

Sample Number	Date Collected	Collection Site	Weight (g)	Length (mm)	Sex	Age	Aging Method	Maturity
Northern squawfish:								
1828	Aug. 25, 1981	Columbia Km 47.5	1400	460	F	8	SC	Mature
1829	Aug. 25, 1981	Columbia Km 47.5	1100	432	F	7	SC	Mature
1833	Aug. 25, 1981	Columbia Km 47.5	780	367	M	6	SC	Mature
1861	Aug. 26, 1981	Columbia Km 54.2	1120	432	M	7	SO	Mature
1862	Aug. 26, 1981	Columbia Km 54.2	800	376	F	6	SO	Mature
1990	Sept. 4, 1981	Columbia Km 8.0*	660	353	M	6	SF	Immature
2002	Sept. 5, 1981	Columbia Km 8.6*	720	371	F	6	SO	Mature
2003	Sept. 5, 1981	Columbia Km 8.1*	850	426	F	7	SO	Mature
Walleye:								
1830	Aug. 25, 1981	Columbia Km 47.5	330	393	F	4	SO	Immature
1831	Aug. 25, 1981	Columbia Km 47.5	940	420		5	SO	
1834	Aug. 25, 1981	Columbia Km 47.5	1640	549	F	7	SO	Mature
1857	Aug. 26, 1981	Columbia Km 54.2	940	420	M	5	SO	Mature
1858	Aug. 26, 1981	Columbia Km 54.2	1040	436	M	5	SO	Mature
1944	Sept. 1, 1981	Columbia Km 8.0*	450	345	M	4	SO	Immature
1945	Sept. 1, 1981	Columbia Km 8.0*	560	375	M	4	SO	Immature
1949	Sept. 2, 1981	Columbia Km 8.0*	440	352		4	SO	Immature
1989	Sept. 4, 1981	Columbia Km 8.0*	580	367	M	4	SF	Immature

* considered to be "Waneta" for statistical analyses

APPENDIX XIV

Concentrations of Hg (ug/g wet weight) measured in fish collected from the Columbia River by R. L. & L. Environmental Services, August-September, 1981.

Species and Sample Number	Provincial Laboratory	Federal (EPS) Laboratory
Bridgelip sucker:		
2049	.10	.08
Kokanee:		
1838	.06	.08
1843	.06	.10
1863	.16	.12
1864	.11	.10
1865	.10	.10
1866	.15	.12
1956	<.05	.05
1957	<.05	.04
1958	<.05	.05
1959	<.05	.07
1960	<.05	.05
1961	<.05	.06
1962	<.05	.05
1963	<.05	.06
1964	<.05	.05
Largescale suckers:		
1832	.10	.11
1835	.18	.19
1836	<.05	.07
1837	.08	.08
Mountain whitefish:		
1846	.09	.13
1847	.09	.15
1848	.11	.16
1855	.15	.14
1951	.21	.15
1952	.20	.15
1983	.10	.13
1984	.12	.15
1991	.14	.16
2008	.09	.09

Appendix XIV (Cont'd)

Species and Sample Number	Provincial Laboratory	Federal (EPS) Laboratory
Northern squawfish:		
1828	.42	.48
1829	.38	.42
1833	.50	.70
1861	.82	.68
1862	.51	.41
1990	.32	.35
2002	.32	.33
2003	.55	.57
Walleye:		
1830	.26	.30
1831	.21	.23
1834	.25	.33
1857	.28	.24
1858	.28	.28
1944	.55	.45
1945	.32	.25
1949	.40	.36
1989	.26	.28

APPENDIX XV

Concentrations of Hg in livers of fish collected from the Columbia River by R. L. & L. Environmental Services, August - September, 1981. Most samples are composites from two or more fish. Values are expressed as ug/g wet weight.

Species	Sample Numbers	Hg
Bridgelip sucker	2049	<.05
Kokanee	1838	.08
	1843	.08
	1863,1864,1865,1866	.12
	1956,1964	.05
Largescale sucker	1835,1836,1837	.19
Mountain whitefish	1846,1847,1848,1855	.23
	1951,1952	.58
	1983,1984,1991	.31
Northern squawfish	1828,1829,1833	.20
	1861,1862	.16
	1990	.26
	2002,2003	.73
Walleye	1830,1831,1834	.26
	1857,1858	.41
	1944,1945,1949	.29

APPENDIX XVIa

Concentrations (ug/g wet weight) of Cd, Cu, Pb and Zn measured in muscle of fish collected by R. L. & L. Environmental Services, August - September, 1981.

Species and Sample Number	Cd	Cu	Pb	Zn
Bridgelip sucker:				
2049	<.011	.90	.015	4.5
Kokanee:				
1838	<.0085	.93	.015	5.3
1843	<.0092	.96	.12	6.4
1863	<.010	1.2	.023	5.5
1864	<.0096	1.0	.015	7.5
1865	<.010	1.1	.016	5.3
1866	<.010	.77	.013	6.0
1956	<.0089	1.5	.048	12.
1957	<.0087	1.6	.019	11.
1958	<.011	1.9	.015	11.
1959	<.0095	1.3	.011	12.
1960	<.010	1.4	<.010	9.8
1961	<.011	1.6	.046	14.
1962	<.010	1.9	.022	9.6
1963	<.0092	1.7	.022	6.9
1964	<.0095	2.1	<.010	9.4
Largescale sucker:				
1832	<.0085	.54	.11	6.3
1835	<.0099	.75	.052	6.1
1836	<.0091	.62	.12	6.6
1837	<.0088	.58	.065	6.9
Mountain whitefish:				
1846	<.013	.57	<.013	5.3
1847	<.014	.99	<.014	4.7
1848	<.013	.70	<.013	4.5
1855	<.014	.48	.033	4.7
1951	<.014	.70	.090	4.4
1952	.015	1.2	.067	6.2
1983	<.013	.68	.056	3.6
1984	<.014	.82	.17	4.8
1991	<.014	.70	.071	5.3
2008	<.014	.85	.18	4.7

Appendix XVIa (Cont'd)

Species and Sample Number	Cd	Cu	Pb	Zn
Northern squawfish:				
1828	<.0090	.53	.088	5.3
1829	<.0085	.73	.043	5.7
1833	<.0098	1.2	.014	5.9
1861	<.010	.51	.017	5.1
1862	<.0085	.69	<.009	4.6
1990	<.0098	1.7	.093	3.6
2002	<.0098	1.4	.15	5.1
2003	<.011	1.3	.13	5.8
Walleye:				
1830	<.010	1.9	.036	5.3
1831	<.0095	1.7	.046	4.7
1834	<.012	1.3	.022	6.3
1857	<.010	.41	.060	5.1
1858	<.011	.47	.039	4.0
1944	<.0092	.56	.048	4.0
1945	<.0099	.40	.032	5.1
1949	<.010	1.1	.030	4.1
1989	<.011	1.1	.036	4.2

APPENDIX XVIb

Concentrations (ug/g wet weight) of other metals measured in muscle of fish collected by R. L. & L. Environmental Services, August - September, 1981.

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Bridgelip sucker:						
2049	<1.1	<.032	<.16	2.5	.16	.20
Kokanee:						
1838	<.85	<.026	.14	2.7	<.017	.044
1843	<.92	<.028	.16	4.9	.033	.13
1863	<1.0	<.031	.21	12.	.035	.082
1864	<.96	<.029	.21	6.7	.046	.20
1865	<1.0	<.031	<.15	2.7	<.020	.12
1866	1.2	<.031	<.16	3.6	.038	.17
1956	<.89	.087	.14	10.	.12	.43
1957	<.86	.074	.19	6.9	.087	.47
1958	<1.0	.062	.16	6.3	.069	.46
1959	<.95	.049	.16	5.5	.076	.44
1960	<1.0	.065	<.15	6.7	.074	.47
1961	<1.1	.089	.17	5.4	.11	.56
1962	<1.0	.098	.17	7.5	.11	.60
1963	<.70	.033	<.11	4.0	.066	.33
1964	<.95	.030	.16	7.5	.024	.13
Largescale sucker:						
1832	<.83	.057	<.13	2.0	.32	.40
1835	<.99	.053	.16	2.8	.25	.43
1836	<.91	.044	<.14	3.9	.23	.23
1837	<.88	.065	<.13	2.3	.24	.34
Mountain whitefish:						
1846	<1.3	<.039	<.20	3.0	<.026	.14
1847	<1.4	<.041	<.21	3.5	<.028	.069
1848	1.5	<.039	<.20	3.6	.058	.29
1855	<1.4	<.041	<.21	3.6	<.028	.19
1951	<1.1	<.033	<.17	9.0	.024	.056
1952	<1.1	<.034	<.17	8.8	.050	.12
1983	<1.3	<.038	<.19	5.1	.030	.058
1984	<1.4	<.041	<.20	9.1	.072	.19
1991	<1.4	<.041	<.21	6.6	.03	.085
2008	<1.4	<.041	<.21	4.3	.21	.51

Appendix XVIb (Cont'd)

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Northern squawfish:						
1828	<.90	.076	.17	1.8	.051	.25
1829	.88	.097	.16	2.7	.067	.31
1833	.99	.047	<.15	2.8	.047	.32
1861	<1.0	.056	<.16	2.7	.059	.41
1862	<.84	.046	.13	1.8	.035	.26
1990	<.99	.16	.20	5.8	.079	.22
2002	1.1	.09	.18	6.0	.10	.30
2003	<1.1	.20	.25	15.	.15	.35
Walleye:						
1830	<1.0	<.031	.24	2.0	.080	.047
1831	<.95	<.029	.19	2.2	.037	.074
1834	1.2	<.034	.24	2.3	.061	.063
1857	<1.0	<.030	.17	1.6	.033	<.040
1858	<1.1	<.033	<.17	1.4	.027	.10
1944	<.92	<.028	.17	2.0	.031	<.037
1945	1.0	<.030	.26	3.6	.040	.064
1949	<1.0	<.030	.19	1.9	.031	.044
1989	<1.1	<.034	.17	2.0	.031	.053

APPENDIX XVIIa

Concentrations (ug/g dry weight) of Cd, Cu, Pb and Zn measured in muscle of fish collected by R. L. & L. Environmental Services, August - September, 1981.

Species and Sample Number	Cd	Cu	Pb	Zn
Bridgelip sucker:				
2049	<.050	4.2	.070	21.
Kokanee:				
1838	<.049	5.4	.089	30.
1843	<.049	5.1	.66	34.
1863	<.049	5.5	.11	26.
1864	<.050	5.4	.080	39.
1865	<.047	4.9	.076	25.
1866	<.048	3.6	.058	28.
1956	<.049	8.5	.27	64.
1957	<.050	9.4	.11	61.
1958	<.050	9.0	.070	51.
1959	<.049	6.6	.059	61.
1960	<.050	7.1	<.050	49.
1961	<.049	7.0	.21	61.
1962	<.048	9.2	.11	46.
1963	<.048	8.8	.12	36.
1964	<.048	11.	<.048	48.
Largescale sucker:				
1832	<.048	3.1	.63	35.
1835	<.048	3.6	.25	30.
1836	<.049	3.3	.65	36.
1837	<.049	3.2	.36	39.
Mountain whitefish:				
1846	<.047	2.1	<.047	19.
1847	<.046	3.3	<.046	16.
1848	<.048	2.6	<.048	17.
1855	<.047	1.6	.11	16.
1951	<.048	2.4	.31	15.
1952	.062	4.9	.28	26.
1983	<.047	2.6	.21	13.
1984	<.046	2.8	.57	16.
1991	<.047	2.4	.24	18.
2008	<.047	2.9	.62	16.

Apppendix XVIIa (Cont'd)

Species and Sample Number	Cd	Cu	Pb	Zn
Northern squawfish:				
1828	<.047	2.8	.46	28.
1829	<.049	4.2	.25	33.
1833	<.048	5.8	.067	29.
1861	<.048	2.4	.077	24.
1862	<.049	4.0	<.049	27.
1990	<.047	7.9	.44	17.
2002	<.048	6.8	.74	25.
2003	<.049	6.0	.60	26.
Walleye:				
1830	<.048	8.9	.17	25.
1831	<.048	8.3	.23	23.
1834	<.049	5.7	.093	27.
1857	<.048	2.0	.29	25.
1858	<.050	2.1	.18	18.
1944	<.048	2.9	.25	21.
1945	<.047	1.9	.15	24.
1949	<.047	5.3	.14	19.
1989	<.050	4.7	.16	19.

APPENDIX XVIIb

Concentrations (ug/g dry weight) of other metals measured in muscle of fish collected by R. L. & L. Environmental Services, August - September, 1981.

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Bridgelip sucker:						
2049	<5.0	<.15	<.75	12.	.75	.94
Kokanee:						
1838	<4.9	<.15	.81	15.	<.099	.25
1843	<4.9	<.15	.85	26.	.18	.71
1863	<4.9	<.15	1.0	55.	.17	.39
1864	<5.0	<.15	1.1	35.	.24	1.0
1865	<4.7	<.14	<.71	13.	<.095	.55
1866	5.5	<.15	<.73	17.	.17	.77
1956	<4.9	.48	.80	56.	.64	2.4
1957	<5.0	.43	1.1	40.	.50	2.7
1958	<5.0	.29	<.75	30.	.33	2.2
1959	<4.9	.25	.81	28.	.40	2.3
1960	<5.0	.33	<.75	33.	.37	2.3
1961	<4.9	.40	.74	24.	.49	2.5
1962	<4.8	.47	.81	35.	.53	2.9
1963	<3.7	.17	<.55	21.	.35	1.7
1964	<4.8	.15	.82	38.	.12	.67
Largescale sucker:						
1832	<4.8	.32	<.70	11.	1.8	2.3
1835	<4.8	.26	.80	13.	1.2	2.1
1836	<4.9	.24	<.73	21.	1.2	1.2
1837	<4.9	.36	<.74	13.	1.3	1.9
Mountain whitefish:						
1846	<4.7	<.14	<.70	11.	<.094	.51
1847	<4.6	<.14	<.69	12.	<.093	.23
1848	5.4	<.15	<.73	13.	.21	1.1
1855	<4.7	<.14	<.70	12.	<.094	.65
1951	<3.8	<.11	<.57	31.	.083	.19
1952	<4.8	<.14	<.71	37.	.21	.49
1983	<4.7	<.14	<.71	19.	.11	.22
1984	<4.6	<.14	<.69	31.	.25	.66
1991	<4.7	<.14	<.70	23.	.10	.29
2008	<4.7	<.14	<.71	15.	.73	1.8

Appendix XVIIb (Cont'd)

Species and Sample Number	Al	Ba	Cr	Fe	Mn	Sr
Northern squawfish:						
1828	<4.7	.40	.91	9.4	.27	1.3
1829	5.0	.56	.93	16.	.38	1.8
1833	4.8	.23	<.72	14.	.23	1.5
1861	<4.8	.26	<.72	13.	.27	1.9
1862	<4.9	.26	.78	11.	.21	1.5
1990	<4.7	.75	.94	28.	.38	1.1
2002	5.1	.44	.86	29.	.49	1.5
2003	<5.0	.88	1.1	65.	.68	1.6
Walleye:						
1830	<4.8	<.14	1.1	9.3	.37	.22
1831	<4.8	<.14	.96	11.	.19	.37
1834	5.0	<.14	1.0	9.7	.26	.27
1857	<.48	<.14	.79	7.9	.16	<.19
1858	<5.0	<.15	<.75	6.3	.13	.46
1944	<4.8	<.14	.86	10.	.16	<.19
1945	4.9	<.14	1.3	17.	.19	.30
1949	<4.7	<.14	.87	9.1	.15	.21
1989	<5.0	<.15	.77	9.0	.14	.23

APPENDIX XVIII

Concentrations of metals (ug/g) measured in a sturgeon collected from the Columbia River at Waneta on May 19, 1982.

Metal	Wet Weight Concentration	Dry Weight Concentration
Mercury	.31	.56
Cadmium	<.55	<1.0
Copper	1.1	2.0
Lead	1.1	2.0
Zinc	11.	19.
Aluminum	3.9	7.0
Barium	<.55	<1.0
Chromium	<.55	<1.0
Iron	52.	93.
Manganese	.55	1.0
Strontium	<.55	<1.0

APPENDIX XIX

Sampling information and some biological characteristics of fish collected from the Columbia River in 1983. FS = fall spawner, SS = spring spawner, I = immature, other abbreviations as in Appendix VIII.

Sample Number	Date Collected	Collection Site	Weight (g)	Length (mm)	Sex	Age	Aging Method	Maturity
Mountain whitefish:								
4801	Sept. 6, 1983	Trail to Beaver Creek	565	365	F	5	SC	FS
4802	Sept. 6, 1983	Trail to Beaver Creek	530	363	M	6	SC	FS
4803	Sept. 6, 1983	Trail to Beaver Creek	310	300	M	4	SC	FS
4804	Sept. 6, 1983	Trail to Beaver Creek	30	185	-	1+	SC	I
4805	Sept. 6, 1983	Trail to Beaver Creek	35	190	-	1+	SC	I
4806	Sept. 6, 1983	Trail to Beaver Creek	35	180	-	1+	SC	I
4807	Sept. 6, 1983	Trail to Beaver Creek	20	175	-	1+	SC	I
4808	Sept. 6, 1983	Trail to Beaver Creek	15	160	-	1+	SC	I
4809	Sept. 6, 1983	Trail to Beaver Creek	20	170	-	1+	SC	I
4810	Sept. 7, 1983	Rock Island to Waneta	500	370	F	6	SC	FS
4811	Sept. 7, 1983	Rock Island to Waneta	610	370	F	6	SC	FS
4812	Sept. 7, 1983	Rock Island to Waneta	405	332	M	3	SC	?
4813	Sept. 7, 1983	Rock Island to Waneta	515	375	F	6	SC	FS
4814	Sept. 7, 1983	Rock Island to Waneta	115	187	-	1+	SC	I
4815	Sept. 7, 1983	Rock Island to Waneta	100	180	-	1+	SC	I
4816	Sept. 7, 1983	Rock Island to Waneta	95	180	-	1+	SC	I
4817	Sept. 7, 1983	Rock Island to Waneta	100	184	-	2	SC	I
4818	Sept. 7, 1983	Rock Island to Waneta	115	177	-	1+	SC	I
4819	Sept. 7, 1983	Rock Island to Waneta	700	385	F	5	SC	FS
4820	Sept. 7, 1983	Rock Island to Waneta	25	110	-	0+	SC	I
Rainbow trout:								
4821	Sept. 7, 1983	Rock Island to Waneta	340	280	-	R	SC	I
4822	Sept. 7, 1983	Trail to Rock Island	320	300	-	2	SC	I
4823	Sept. 7, 1983	Trail to Rock Island	1250	480	M	4	SO	I
4824	Sept. 7, 1983	Trail to Rock Island	1640	530	F	R	SO	SS
4825	Sept. 7, 1983	Trail to Rock Island	1040	430	F	3	SO	SS
4826	Sept. 7, 1983	Trail to Rock Island	425	315	-	3	SC	I
4827	Sept. 7, 1983	Trail to Rock Island	280	270	-	2	SC	I
4828	Sept. 7, 1983	Trail to Rock Island	460	315	-	3	SC	I
4829	Sept. 7, 1983	Trail to Rock Island	430	325	-	-	SC	I
4830	Sept. 7, 1983	Trail to Rock Island	430	324	-	2	SC	I
4831	Sept. 7, 1983	Trail to Rock Island	400	308	F	3	SC	I
4832	Sept. 7, 1983	Trail to Rock Island	220	259	-	R	SC	I
4833	Sept. 7, 1983	Trail to Rock Island	250	274	F	3	SC	I
4834	Sept. 7, 1983	Trail to Rock Island	250	260	F	2	SC	I
4835	Sept. 7, 1983	Trail to Rock Island	230	255	-	2	SC	I

APPENDIX XX

Concentrations of Hg (ug/g wet weight) measured in fish collected from the Columbia River, September 6-7, 1983.

Species and Sample Number	Provincial Laboratory	Federal (WQB) Laboratory
Mountain whitefish:		
4801	.14	.05
4802	.18	.05
4803	.09	.07
4804	<.05	
4805	<.05	
4806	<.05	
4807	<.05	
4808	<.05	
4809	<.05	
4810	.22	.20
4811	.20	.13
4812	.13	.10
4813	.19	.17
4814	<.05	.01
4815	<.05	.01
4816	<.05	.01
4817	.06	.01
4818	<.05	.01
4819	.10	.10
4820	<.05	
Rainbow trout:		
4821	<.05	.02
4822	<.05	.02
4823	<.05	.04
4824	.10	.08
4825	.07	.05
4826	.05	.03
4827	.06	.02
4828	<.05	.02
4829	<.05	.02
4830	<.05	.02
4831	<.05	.02
4832	<.05	.02
4833	<.05	.03
4834	<.05	.02
4835	<.05	.02

APPENDIX XXI

Mercury measured in composite samples of livers from mountain whitefish collected in 1983. Values are expressed as ug/g wet weight.

Sample Numbers	Hg
4801,4802,4803	.62
4810,4811,4812	.61
4813,4819	.32

APPENDIX XXIIa

Concentrations (ug/g wet wt) of Cd, Cu, Pb and Zn measured in muscle of fish collected from the Columbia River, September 6-7, 1983.

Species and Sample Number	Cd	Cu	Pb	Zn
Mountain whitefish:				
4801	<.02	-	<.1	4.5
4802	.04	.31	.3	6.2
4803	<.02	.42	<.1	6.0
4810	.04	.46	.2	6.0
4811	.02	.58	.2	5.5
4812	.02	.58	.2	4.9
4813	.10	.23	<.1	3.6
4814	<.02	.25	.1	6.0
4815	<.02	.53	<.1	8.0
4816	<.02	.63	<.1	6.1
4817	.02	.66	<.1	7.4
4818	<.02	.39	<.1	6.3
4819	<.02	.37	<.1	4.3
Rainbow trout:				
4821	<.02	.74	<.1	6.5
4822	<.02	.60	.2	7.1
4823	<.02	.29	<.1	4.5
4824	<.02	.39	<.1	3.6
4825	<.02	.76	<.1	5.1
4826	<.02	.57	<.1	6.1
4827	<.02	.54	<.1	5.2
4828	<.02	.76	.1	9.0
4829	<.02	.51	<.1	5.1
4830	<.02	.82	<.1	8.0
4831	<.02	.69	<.1	9.7
4832	<.02	.42	<.1	5.5
4833	<.02	.67	<.1	6.1
4834	<.02	.33	.2	4.9
4835	<.02	.72	<.1	7.7

APPENDIX XXIIb

Concentrations (ug/g wet wt) of other metals measured in muscle of fish collected from the Columbia River, September 6-7, 1983.

Species and Sample Number	Cr	Fe	Mn	Sr
Mountain whitefish:				
4801	-	-	-	<.2
4802	<.20	12.7	<.2	.2
4803	<.20	10.3	<.2	<.2
4810	<.20	12.1	<.2	.4
4811	<.20	8.2	.2	.2
4812	<.20	11.3	.2	.5
4813	<.20	11.3	<.2	.5
4814	<.20	4.7	.2	.9
4815	<.20	5.9	<.2	.4
4816	<.20	6.8	<.2	<.2
4817	<.20	5.4	.2	.5
4818	<.20	3.9	<.2	<.2
4819	<.20	8.8	<.2	<.2
Rainbow trout:				
4821	<.20	6.5	<.2	<.2
4822	<.20	4.9	<.2	.3
4823	<.20	2.7	<.2	<.2
4824	<.20	4.5	<.2	<.2
4825	<.20	3.9	<.2	<.2
4826	<.20	4.9	<.2	<.2
4827	<.20	3.2	<.2	.4
4828	<.20	6.9	<.2	.4
4829	<.20	3.1	<.2	.2
4830	<.20	7.3	<.2	<.2
4831	<.20	6.0	<.2	<.2
4832	<.20	2.4	<.2	.4
4833	<.20	4.9	<.2	<.2
4834	<.20	2.2	<.2	.5
4835	<.20	5.9	<.2	<.2

APPENDIX XXIII

Concentrations of metals (ug/g wet weight) in livers of walleye analyzed as part of Cominco's moniotoring program. Tissue was taken from fish caught by anglers at Waneta in 1984. Fish weights were in the 2 - 4.5 kg range.

Sample Number	Cd	Pb	Zn	Hg
0001	12	4	74	.09
0002	5	2	33	.05
0003	15	<1	85	.11
0004	10	<1	100	.07
0005	8	8	85	.05
0006	11	9	89	.08
0007	11	<1	75	.13
0008	5	<1	58	.05
0009	11	4	77	.19
0010	3	6	39	.10
0011	5	<1	62	.07
0012	13	<1	86	.06
0013	11	<1	110	.07
0014	4	<1	34	.01
0015	11	<1	100	.08
0016	8	1	67	.08
0017	10	5	76	.11
0018	12	8	120	.05
0019	13	<1	100	.06
Mean	9	3	77	.08
S. D.	4	3	24	.04
Minimum	3	<1	33	.01
Maximum	15	9	120	.19

APPENDIX XXIV

Interlaboratory comparisons of analyses for metals performed on fish collected in 1980. Values are expressed as ug/g wet weight. EPS = Environmental Protection Service Laboratory, WQB = Water Quality Branch (Vancouver) Laboratory

Sample	Cd		Cu		Fe		Mn		Pb		Zn	
Number	EPS	WQB	EPS	WQB	EPS	WQB	EPS	WQB	EPS	WQB	EPS	WQB
6362	<.011	<.15	.52	.53	2.7	2.5	.26	.29	.16	.54	7.3	6.1
6374	.019	<.15	1.6	.67	3.0	3.1	.39	.35	1.6	1.4	6.5	6.7
6451	.022	<.15	.82	.93	3.6	3.1	.40	.56	1.2	1.6	7.4	6.8
6455	.11	<.15	.72	.33	1.8	1.8	.47	.36	.41	.60	5.8	5.4
6465	.016	<.15	.63	.64	3.0	3.2	.45	.73	.48	1.3	11.	10.
6468	.070	<.15	.57	.78	3.8	5.2	.50	.60	.25	.80	11.	9.5
6469	.013	<.15	1.4	1.1	4.8	5.3	.67	.68	.84		9.9	8.2
6356	<.013	<.15	1.1	1.3	7.0	7.0	.16	.20	.09	.53	4.4	4.5
6358	<.011	<.15	.62	.57	11.	11.	.13	.19	.15	.35	4.1	4.1
6464	.020	<.15	.87	.86	4.6	4.8	.17	.19	.03	.38	5.9	5.4
6367	.065	<.15	1.4	.78	5.9	6.5	.11	.21	.27	.75	5.4	5.5

APPENDIX XXV

Replicate metal analyses performed on homogenates of whole mountain whitefish. Seven fish (sample numbers 4804, 4805, 4806, 4807, 4808, 4809 and 4820 were composited for these analyses. Values are expressed as ug/g wet weight.

Cd	Cu	Cr	Fe	Pb	Mn	Zn	Sr	Hg
.03	.75	.26	7.8	.1	<.2	5.8	<.2	.04
.02	.73	.26	7.4	.1	<.2	5.8	<.2	.04
<.02	.75	.34	8.0	.1	<.2	6.9	<.2	.04
.03	.76	.34	8.5	.2	<.2	6.7	<.2	.04
.03	.70	.36	8.0	.2	<.2	7.1	<.2	.04
.08	.80	.35	7.9	.2	<.2	5.9	<.2	.04
<.02	.67	.27	7.8	.1	<.2	7.4	<.2	.04

APPENDIX XXVI

Concentrations of hepatic metallothionein and heavy metals in livers of rainbow trout collected in 1983.

Sample Number	Metallothionein (nanomoles/g)	Cd	Cu	Zn
		(ug/g wet weight)		
4821	107	.9	69	32
4822	192	2.1	85	33
4823	121	1.5	74	22
4824	195	3.3	34	32
4825	126	2.4	28	28
4826	117	1.4	46	27
4827	104	.7	65	21
4828	103	1.1	75	26
4829	152	2.2	67	27
4830	90	.9	56	28
4831	80	1.5	68	26
4832	81	.4	43	31
4833	128	.6	36	30
4834	136	1.6	95	24
4835	131	2.4	107	30